CTBTO PREPARATORY COMMISSION

Science and Technology 2021 Conference
Scientific Advances in CTBT Monitoring and Verification

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Review of Presentations and Outcomes of the
Comprehensive Nuclear-Test-Ban Treaty:
Science and Technology 2021 Conference

Vienna, Austria
28 June–2 July 2021

EXECUTIVE SUMMARY

Executive Summary

1. SnT2021: A Hybrid Virtual Conference

SnT2021, the sixth conference in the CTBT: Science and Technology series, was held on 28 June–2 July 2021. The conference was devoted to scientific and technological developments that are important to the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) and its monitoring network, with the main goal of identifying opportunities and methods for improving nuclear test monitoring and verification. SnT2021 was the largest ever, with more than 1600 participants. In all, 89 oral presentations were given, and slide and video files to 365 posters were uploaded. Further statistics are provided in Appendix 2 of this report.

The conference was held in the midst of the COVID-19 global pandemic. Travel restrictions and limitations on physical attendance necessitated a change in format. The opening day was a hybrid event, combining a limited in-person audience of about 200 people in the Hofburg Palace in Vienna, Austria with a virtual audience around the world. Even on the first day, most participation was online, with many presenters and more than 1000 attendees participating off site. The remainder of the conference was purely virtual, with the Vienna International Centre (VIC) premises serving as a hub to run the conference sessions.

Posters were uploaded ahead of the conference, giving them an extended exposure. Presenters had the opportunity to participate in 10 round table sessions that attracted a lot of attention, with some enjoying the participation of more than 250 online attendees. Such exposure of posters is definitely higher than what was common for the 'normal' physical presence conferences of the past. While there are certainly advantages to face-to-face interaction, video rooms and chats enabled attendees to interact with presenters.

The virtual platform of the conference was called vSnT2021 and supported by Superevent B.V. It was available to all registered users on web browsers as well as on mobile devices. During the conference week, an unprecedented number of 1458 participants registered and logged onto this platform. Conference sessions were held in Webex virtual rooms and streamed to live 'stages' supported by vSnT2021. The technical reliability of the platform was high, and there were no major problems during the conference.

While the technical arrangements for the virtual conference were very different from past conferences, the programme largely followed the example of previous successful SnT conferences. For much of the time, three live stages were streamed in parallel, and online participants could easily switch from one session to another. Sessions were run from the VIC, mostly by PTS staff. Every session had a small technical support team of three to four people and a content team comprising the session convener and a Q&A coordinator. All panel discussions consisted of off-site online panellists. For some panels, the moderator was also off-site. In such cases, the PTS convener who was physically present in the session room at the VIC provided support to ensure the smooth conduct of the discussion.

All presenters were strongly encouraged to upload recordings of their presentations before the conference. These files were uploaded to the Indico database that served the conference. For oral presentations, either the recordings or live presentations were used during the sessions. The transition between live and recorded content was handled by the Webex PTS teams and ran smoothly, with almost no technical problems. Sessions were recorded and made available as YouTube videos. Appendix 1 of this report includes the conference programme, with the appropriate YouTube links to sessions.

The uploaded files of oral and poster presentations constitute an invaluable resource. In this report, the designations that appear in the summaries of the talks, panel discussions and presentations are hyperlinked to these uploaded files. Especially for poster presentations, this is a unique modality to retain knowledge that was not available in previous physical conferences. This element of the virtual conference format is very important for the preservation of conference material, and it is strongly recommended that it be retained in future SnT conferences, regardless of format.

The relative number of actual presentations delivered compared with the number of submitted and accepted abstracts was approximately 80 per cent, which is higher in comparison with previous SnT conferences. For posters, only those for which the authors uploaded files are considered as being presented and included in this report. This level of compliance is remarkable, especially given the fact that the format of the conference was announced only in February, months after the deadline for the submission of abstracts.

While it is a fervent hope that future SnT conferences will be held in person, there are important aspects of the virtual conference format that are beneficial and worth continuing. Online presentations and attendance can enable those who cannot travel to participate. This enriches the opportunities for unique presentations at the conference. Early uploading of poster files and poster round tables resulted in much longer and wider exposure of posters. There is also an improved level of documentation accompanying the presentations with uploaded poster and slide files and recorded talks and discussions. These elements should be retained in future conferences.

2. Opening Day, Invited and Highlight Talks, Panel Discussions

Much of the content of the SnT conferences has been based on submitted abstracts. However, Invited Talks and panel discussions constituted the backbone of the SnT2021 conference and are an important mechanism to address important questions to the CTBTO, including those on issues that are less well covered by the submitted abstracts. In SnT2021, the two main unique themes were the 25th anniversary of the opening for signature of the Treaty, which provided an opportunity to review scientific and technological advancements and project what developments can be expected, and the COVID-19 pandemic, which served as a resilience test for the monitoring system.

The 25th anniversary of the Treaty was addressed during the opening day discussions and in a series of panels and Invited Talks. Chapter 2 of this report reviews the opening day discussions. The opening message by Executive Secretary Lassina Zerbo during Session 1 is given in full, followed by a description of the ceremonial opening and political remarks and the facilitated dialogue "CTBT@25 Years: Evolution of the CTBT, the Organization and Its Technologies and CTBT's Model Function of Inclusion and Science Cooperation". Session 2 of the opening day included a Keynote Address by Dimitri Kusnezov, entitled "Artificial Intelligence: What, Why and How It Could Transform Our Missions"; the panel discussion "Space Science and Technology for Global Sustainable Development, Peace and Security"; and the European Union–CTBTO panel discussion "Securing a Nuclear-Test-Free World for Youth and the Next Generations". Chapter 2 also addresses youth engagement, which was emphasized throughout the conference.

Chapter 3 summarizes the Invited Talks on the 25th anniversary of the Treaty. These talks constitute a very valuable resource, bringing together wide perspectives on the development of the monitoring network over the past 25 years, discussions of current challenges and recommendations for the future. The

Invited Talks include:

- I01-722 – Challenges and Achievements of Monitoring for Nuclear Test Explosions in the Context of the CTBT, by Paul G. Richards
- I02-718 – The CTBT Hydroacoustic Network at 25 Years, by Martin Lawrence
- I03-714 – 25 Years of Infrasound Monitoring: Achievements and New Challenges, by Elisabeth Blanc
- I04-717 – The IMS Radionuclide Network: A Unique Machine Not Yet Fully Exploited, by Anders Ringbom
- Is6-454 – Machine Learning Prospects for Automatic SHI Processing, by Christos Saragiotis
- Is1-353 – New Applications at the IDC for SHI Expert Technical Analysis, by Ivan Kitov
- P3.5-507 – Is There Potential for Further Enhancing IDC Spectrum Analysis Methods of CTBT Radionuclide Measurements After 25 Years of Progressive Development?, by Boxue Liu
- Is2-283 – Advancements in Hydroacoustic Signal Processing at the IDC During the Past Two Decades and Plans for the Future, by Ronan Le Bras
- Is3-381 – Infrasound Processing System at the IDC, from Rudimentary to Maturity, by Pierrick Mialle
- Is4-332 – Advancements in Atmospheric Transport Modelling at the CTBTO PTS During the Past Two Decades and Plans for the Future, by Jolanta Kusmierczyk-Michulec
- Is7-604 – Review and Outlook of Radionuclide Screening Methods for Discriminating Nuclear Explosion Signals from Normal Radioactivity Background in the Atmosphere, by Theodore Bowyer
- I05-727 – Status of Preparations for the Support of On-Site Inspections, by Peter Labak
- Is5-239 – Development of the First Comprehensive Draft List of Equipment for Use During On-Site Inspections, by Gregor Malich

In addition, three Highlight Talks were given, on the topics The Solid Earth and Its Structure, The Oceans and Their Properties, and The Atmosphere and Its Dynamics. Chapter 4 provides summaries of the following talks:

- H1-720 – Imaging the Earth's Deep Interior Using Seismic Waves, by Barbara Romanowicz
- H2-716 – Improving Ocean Monitoring Through the Expansion of the Global Seismographic Network on the Sea Floor, by John Orcutt
- H3-715 – Predictability of the Evolution of the Earth System and of the Atmosphere: A Historical Perspective and Future Challenges – Weather, Climate and Air Quality, by Guy Brasseur

Chapter 5 covers technical panel discussions marking the 25th anniversary of the Treaty. The panels discussed the challenges facing monitoring system and innovative ways to address these challenges. The seven technical panels include:

- J03 – Lessons from Historical Nuclear Test Explosions and Value of Recorded signals for Monitoring Science
- J04 – Innovation Affecting CTBT: International Monitoring System (IMS Sensors)
- J05 – Innovation Affecting CTBT: IDC Data Analysis (Needs, Ideas and Implementation Pathways)
- J06 – Civil and Scientific Applications: Prospects
- J07 – Regional Data for Treaty Monitoring
- J08 – Human Versus Machine
- J09 – Synergy Among Monitoring Systems to Address Hazard Mitigation and Global Challenges

Introductory Talks preceded some of the technical panels. Talks I06-721 "Civil and Scientific Applications of IMS Data", by Zeinabou Mindaoudou Souley, and I06-719 "Sustainable Development, Disaster Risk Reduction and the CTBTO Verification Regime, by Öcal Necmioğlu, introduced panel

J06. Introductory Talk I08-723 "Knowledge Versus Data", by Stuart Russell, introduced panel J08. Talks I07-529 "Use of Infrasound Data for Early Notification of Volcanic Ash Advisory Centres", by Philippe Hereil, and I09-742 "Welcome to Risk: As We Know It, or Do We?", by Loretta Hieber-Girardet, introduced panel J09.

Chapter 5 also summarizes two Special Talks on the "Anthropocene Epoch" that were given in memory of scientist Paul Crutzen (1933–2021): I10-749 "Multiple Reasons for the Anthropocene: Paul Crutzen's Contribution to Saving Planetary Boundaries", by Hartmut Grassl, and I10-752 "Artificial Radionuclide Fallout: A Marker for the Start of the Anthropocene Epoch", by Colin Waters. In addition, Chapter 5 includes summaries of panel J11 "Communicating Uncertainty Among Scientists to Policy Makers and the Public" and a session on National Data Centres.

3. Oral and Poster Presentations

With the exception of the opening day, all presentations at Snt2021 were given online, either orally or as poster presentations. Abstracts for these presentations were submitted in October 2020–January 2021, and the SnT2021 Book of Abstracts was distributed as an e-book shortly before the conference. A high percentage (about 80 per cent) of the accepted abstracts were presented at the conference. Oral presentations were delivered live online or as pre-recorded files, the posters by uploading short video presentations and slide files and, for presenters who desired it, alsoo by participating in one of the 10 round table poster discussions.

Oral and poster presentations were submitted according to the five conference themes.

Theme 1: The Earth as a Complex System
T1.1 The Atmosphere and Its Dynamics
T1.2 The Solid Earth and Its Structure
T1.3 The Oceans and Their Properties

Theme 2: Events and Nuclear Test Sites
T2.1 Characterization of Treaty-Relevant Events
T2.2 Challenges of On-Site Inspection
T2.3 Seismoacoustic Sources in Theory and Practice
T2.4 Atmospheric and Subsurface Radionuclide Background and Dispersion
T2.5 Historical Data from Nuclear Test Monitoring

Theme 3: Verification Technologies and Technique Application
T3.1 Design of Sensor Systems and Advanced Sensor Technologies
T3.2 Laboratories Including Mobile and Field Based Facilities
T3.3 Remote Sensing, Imagery and Data Acquisition Platforms
T3.5 Data Analysis Algorithms
T3.6 Artificial Intelligence and Machine Learning

Theme 4: Performance Evaluation and Optimization
T4.1 Performance Evaluation and Monitoring of the Full Verification System and Its Components
T4.3 Information Technology, Power Systems and Other Enabling Technologies
T4.4 Network Sustainability
T4.5 Resilience of the CTBT Monitoring Regime, Including Lessons Learned from the COVID-19 Pandemic

Theme 5: CTBT in a Global Context
T5.1 Science in Policy Discussions and Lessons Learned from Other Arms Control Agreements and Arrangements

T5.2 Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals
T5.3 Capacity Building, Education, Communication and Public Awareness

Chapter 6, on the oral and poster presentations, is the largest section of the report, comprising about two thirds of its content. It is organized according to the themes of the conference. Under each theme, highlights of the oral and poster presentations are given, followed by the abstracts of all presentations. Every reference to a presentation in a highlights section is linked to the abstracts and the Indico database. As previously stated, only presentations that were given or for which accompanying files were uploaded to the Indico database of SnT2021 are referred to in this report.

Topic 4.5, on Resilience of the CTBT Monitoring Regime, Including Lessons Learned from the COVID-19 Pandemic, was a unique theme for SnT2021. The global pandemic that began in early 2020 put a substantial amount of strain on many systems, with the CTBT monitoring regime being no exception. At the same time, the crisis has proved to be a significant and valuable resilience test of the functioning of all systems under considerable stress, especially in relation to lockdowns and travel restrictions. This issue was addressed in oral and poster presentations under Topic 4.5, as well as in a dedicated panel discussion (J02) and two unique Special Events (M1, M2), where reflections from stations, NDCs and the PTS were shared. Station operators have faced logistical problems, increased shipping times for spare parts, severe travel limitations, difficulties in the shipment of radionuclide samples for quality assurance/quality control (QA/QC), delays in scheduled station calibrations and unstable communications links. Continuous communication, availability and flexibility in supporting station operators were key to managing the network.

4. Relevance to CTBTO Activities and Verification Science

Chapter 7 summarizes the conference highlights with a special focus on those that have specific potential relevance to future CTBTO activities and verification science. Unlike previous chapters, it brings together points raised under different themes, topics, Invited Talks and panel discussions. It is organized according to the subject matter and structured as follows:

1. Sensors and Measurements
    - Radionuclide Technologies
    - Seismic Sensors
    - Infrasound
    - Hydroacoustic Technologies
    - Calibration
2. Power Systems, Data Handling and Communication Systems
3. Maintenance
4. Performance Evaluation and Optimization
5. Resilience of the CTBT Monitoring Regime: The COVID-19 Pandemic
6. Propagation of Signals
7. Atmospheric Transport Modelling
8. Radionuclide Background
9. Processing of Radionuclide Signals
10. Processing of Seismic, Hydroacoustic and Infrasound Data
11. Historical Data and Events, Event Physics and Screening Methods
    - Historical Event Data
    - Announced Nuclear Tests of the Democratic People's Republic of Korea
    - Source Physics and Modelling
    - Screening Methods and Event Parameter Determination

- Explosion at the Port of Beirut in Lebanon (4 August 2020)
- Bulletins and Event Catalogues

12. On-Site Inspection
13. Civil and Scientific Applications

Excerpts from Chapter 7 are presented below as examples of the rich material that was shared at SnT2021. Many important contributions are not included owing to the space constraints of this Executive Summary. The reader is strongly encouraged to consult the full report to truly benefit from this important collection of presentations.

Sensors and Measurements

It is vital that the PTS stays abreast of new developments related to all sensor types in order to maintain its high performance level, ensure network sustainability, and safeguard and improve Treaty verification capability. Panel discussion J04 focused on new generation sensors that may already be available as well as innovative efforts for future developments. Among the topics of discussion were networks of infrasound sensors, combined rotational and directional seismic sensors, modular design hydroacoustic hydrophone stations, science monitoring and reliable telecommunications (SMART) underwater cables and sensors, fibre-optic seismometers and hydrophones, and improved concepts for radionuclide particulate stations and next-generation noble gas systems. Sensors were also addressed under the dedicated Topic 3.1, as well as in presentations under other topics.

Radionuclide Technologies

Currently, most new sensors are in the field of radionuclides. Several next-generation xenon measurement systems with improved detection capability are close to deployment and undergoing calibration, validation and acceptance testing (e.g. MIKS, Xenon International). Two systems have passed the acceptance process successfully (SAUNA III, SPALAX NG). The first SAUNA III system went into operation in September 2021, soon after the SnT conference. During SnT2021, presentations O2.4-510, P3.1-512 and P3.2-518 showcased work on SPALAX NG and future developments of noble gas detection systems. P3.1-434 reported on the testing results of the upgraded detection system of the MIKS complex prototype, while P3.1-616 and O2.4-138 reported on the first phase of acceptance tests of Xenon International. During Invited Talk I04-717, it was suggested that considering the network as a single measurement system would open the horizon for many improvements that can still be made, with respect to measurements as well as data analysis. Results of testing the world's first radioxenon array were reported in P3.1-375. The array consists of five SAUNA CUBE units, placed 200–500 km apart.

The technology used for the collection of particulate radioactivity is well established and robust, but largely increasing air volume requires a technology change. P3.1-669 discussed the integration of an electrostatic precipitator into RASA 2.0 for radionuclide particle collection. P3.1-299 discussed the integration of a next-generation automated air sampler in Cinderella G2. Work on the materials for improved adsorption of xenon, such as metal exchanged zeolites relevant for uptake and purification performance, was described in O3.1-316 and P3.1-670.

P3.1-303 presented test implementation of a coincidence detector system for the measurement of particulate samples at the CTBTO Test Station in Vienna. A novel cadmium zinc telluride detector was presented in P3.1-309. Next-generation gamma–gamma coincidence measurements have the potential to significantly improve the confidence of detection of particulate radionuclides that are relevant for nuclear explosion monitoring purposes. P3.1-312 and P3.1-187 described prototype development and experiments. O3.2-482 compared the performance of different

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

xenon detection systems with high and low resolution for beta–gamma detection. P3.1-216 described development of a silicon beta cell for use as a potential modular replacement for the next-generation Xenon International system.

Seismic Sensors

Few contributions addressed developments in seismic sensors on land. Rotation seismometry sensors were discussed in P3.1-180, which focused on metrological aspects in this developing field. P3.1-666 described a fibre-optic gyroscope for the measurement of rotational ground motion. P2.1-162 suggested using dedicated portable rotation sensors for seismological applications to improve the resolution of the isotropic seismic moment tensor by analysing rotational ground motion. One of the main causes of noise in precise long period seismometry is the temperature fluctuation of mechanical elements of devices and sensors. To reduce such noise, P3.1-393 suggested the use of precision small-sized temperature sensors.

Infrasound Sensors

In recent years, an increasing number of low cost infrasound sensors have been developed. P3.1-221 discussed PTS activity to monitor the development of such sensors in order to identify new opportunities for the future of the monitoring system. P3.1-618 described the expansion of the infrasound network by using inexpensive digital condenser microbarographs. Adding more sensors to infrasound arrays increases their resolving power, facilitating the detection of weak signals and the identification of multiple simultaneous waves from different directions. P3.1-665 showed that the detail and resolving power of array analyses can be improved dramatically by increasing the number of sensors in the array. P3.1-520 presented a wind noise reduction system that meets all requirements and topology constraints of the infrasound stations in the IMS network.

Hydroacoustic Technologies

P4.4-276 summarized the ongoing projects of the IMS on solutions for the re-establishment of damaged sections, risk mitigation studies and protective measures for hydrophone hydroacoustic sensors. P1.3-270 presented the development of a new modular design concept for next-generation hydrophone stations that enables the replacement of failing components in situ.

The great potential for fibre-optic technologies, including shallow borehole optical tiltmeters, fibre-optic strain sensors and distributed acoustic sensing (DAS), was emphasized in panel discussion J04. Over the last decade, methods have been developed that use laser techniques with existing telecommunications cables to measure seismic, acoustic and temperature signals with surprising sensitivity, to sub-metre spatial resolution in some cases and with cables longer than 100 km in others. O3.1-384 discussed the potential for integration of distributed optical fibre sensors into IMS hydroacoustic systems. O1.3-705 provided an update on SMART subsea cables for monitoring the ocean and earth on a planetary scale. P3.1-293 compared observations performed by DAS using a fibre-optic submarine cable with data from co-located hydrophones.

Calibration

The topic of calibration is cross-cutting among all technologies. It is especially important in a global monitoring system, where contributions from widespread sensors are gathered and fused to reach inferences about events. Calibration issues were emphasized in panel J04, which noted that traceability by national calibration hierarchy, quality assurance and monitoring by comparison measurements are important. A proposal was made to advance the traceability of the IMS sensors to the SI system and the internationally recognized standards. O4.1-213 described the efforts of the metrology community to improve the measurement standards that underpin data quality in CTBT monitoring activities. This aims to foster greater contact with relevant stakeholders, with the objective of establishing primary measurement standards. The described project will also address requirements for reference sensors that link laboratory calibration capabilities to field requirements for measurement traceability.

P3.1-243 presented a web application developed at the PTS for the calibration of geophysical systems that is applicable across all IMS waveform technologies. O3.1-467 presented an external calibrator system that is nearing maturity. The integrated infrasound sensor–external calibrator package behaves as a self-calibrating sensor. P4.1-336 described a system that generates comprehensive network intelligence that informs upstream quality assurance efforts. P1.2-631 estimated the occurrence of suspect instrument intervals. P3.5-250 discussed tools for automatic quality checks of calibration files for radionuclide particulate stations. P3.5-234 examined quality control measurements that are taken to monitor and correct for gain drifts in radioxenon nuclear detectors with a ^{137}Cs source. P3.5-280 described a method to monitor gain changes in radioxenon beta–gamma sensors. While several gamma ray lines can be used, the beta detector does not produce clear peaks. The use of counting statistics from the Compton scatter line gives reliable results. P3.1-485 demonstrated the capability to produce gaseous radionuclides for quality assurance and calibration purposes. P4.1-196 described how to track gain drifts in gamma radiation sensors. P1.3-284 described a method to improve the estimate of the relative location of IMS hydrophones. This work demonstrates how knowing the accurate deployment position of each hydrophone in the triplet of an IMS hydrophone station is essential to obtaining the accurate location of an event by back azimuth estimation. O3.1-579 focused on the testing of an innovative system for calibrating infrasound sensors.

Power Systems, Data Handling and Communication Systems

Under a mandate to sustain high data availability throughout the IMS network, next-generation power systems have been designed to strengthen the resiliency of IMS stations to catastrophic failures. Presentation O4.3-266 described five standardized IMS power system prototypes that were developed, certified and subjected to thorough factory acceptance testing. The new systems are undergoing long period testing in field conditions. O4.3-514 presented a modular power supply system that is adapted to the IMS network. All of these power systems are equipped with their own state of health information technology system that allows continuous monitoring. P4.3-329 described a solution for the continuous power supply of a seismic station. P4.3-653 presented a model for the incorporation of a stronger energy power system for IMS stations.

Cloud computing has increased significantly over the past several years. Use of the NDC in a box software suite on cloud platforms could expand NDC capabilities and increase NDC use of IMS data by using cloud resources to perform analysis and data pulls, thereby reducing local bandwidth and infrastructure issues (O4.3-167).

P4.3-334 described a new configurator developed for standard station interface (SSI). Good database management practices are important to guarantee issuance of products in real time, with the data protected and available in the main database, servers and backups, avoiding unnecessary traffic that overloads the network (P4.3-066, P4.3-140). P4.3-570 gave an overview of how information from a network management system can be used to analyse outages in data transmission to determine the root cause and identify necessary infrastructure improvements. P4.3-558 discussed challenges in using radio frequency links for intra-site communication at IMS waveform stations.

P4.3-414 described the main design changes to the Experts Communication System (ECS). The ECS is a secure, Internet-accessible application that enables registered users from States Signatories and the PTS to access official CTBTO documents and other material. P4.3-445 described a project to create a new email domain for verification data on a segregated infrastructure. The domain @ctbto.int was chosen for the verification systems.

Maintenance

Despite COVID-19, data availability averaged over all technologies was very high in 2020–2021. Future challenges include an aging IMS network, continued completion and expansion of the network of certified stations under a constant maintenance budget, and no increase in staffing. Several methods were implemented by the IMS Maintenance Unit to improve data availability (O4.4-528). These include equipment standardization, infrastructure improvements, improved equipment sparing, improved hands-on technical training, better documentation and implementation of secure shipping of HPGe detectors.

Sustainment of the IMS hydrophone hydroacoustic network is very challenging. P4.4-276 summarized the ongoing sustainment projects of the IMS through solutions for the re-establishment of damaged sections, risk mitigation studies and protective measures. Innovative modular design solutions to facilitate the repair of underwater components and enhance resilience were described, together with protective measures for onshore electronics.

Work on predictive maintenance and state of health monitoring capability continues (P4.4-152, O4.4-209, P4.4-382), with the goal to detect component failures and develop preventive maintenance techniques for IMS stations. Ongoing work aims to develop models to understand state of health data and trends as well as algorithms to integrate predictive monitoring into the state of health data analysis. O4.4-135 and P4.4-134 reported on the operation of a temporary IMS seismic station during the major upgrade of a seismic array. With minimal impact on seismic monitoring during the upgrade and at a reasonable cost, the temporary array proved to be a valuable investment.

Performance Evaluation and Optimization

Operation and sustainment of a global network of monitoring systems poses substantial challenges. Near real time acquisition and forwarding of continuous and segmented data and the subsequent processing and analysis of data must meet and sustain strict requirements for operational data availability, quality and timeliness. Performance critically depends on enabling technologies such as information technology and power systems. Evaluation and optimization of the performance of the CTBT verification system involves factors such as improvements to efficiency and cost effectiveness, reliability and security. Presentations under Topic 4.1 focused on performance evaluation and modelling, but this subject was also addressed in other sessions, panel discussions and Invited Talks. The COVID-19 pandemic brought unprecedented challenges for the monitoring system. Despite the global pandemic, data availability averaged over all technologies was very high in 2020–2021.

Speakers in panel discussion J04 and Invited Talk I04-717 commented on the benefits of arrays and increasing the number of sensors. With regard to infrasound sensors, it was stated during the panel that the development of low cost/low power sensors can assist in the implementation of arrays to replace single sensors. It was also recommended to increase the use of auxiliary stations. During the Invited Talk, it was noted that due to the short half-lives of the relevant isotopes, the xenon detection coverage of the network needs to increase.

In panel J04, it was suggested that after entry into force, the Conference of the States Parties may consider increasing the number of noble gas systems from 40 to 80, which would greatly improve Treaty verification capability.

The status of the IDC SHI Reengineering project was presented in P4.1-324. The project goal is to create modernized, open source software for SHI processing, while improving the maintainability and extensibility of the system. P4.1-113 stressed the need to update the user guide on IDC processing of SHI data, which was written in 2002. An innovative approach to compute source characteristics of infrasound events was presented in O4.1-624. Localizing events is done by combining the usual Bayesian inference, with sampling over a metamodel. O4.1-519 introduced a fully automated stochastic method for calculating the optimal station distribution inside a permanent or temporary seismic network. P4.1-339 used data of relatively small explosions to assess location accuracy and the estimated magnitude of events recorded by the IMS network. O4.1-121 introduced the Radiation Field Training Simulator (RaFTS), an innovative signal injection methodology. P3.1-115 highlighted the performance of a major upgrade of an infrasound array in a remote location with harsh climate conditions.

NDC Preparedness Exercises (NPEs) are a major opportunity for NDCs to conduct exercises based on a scenario investigation for the detection of nuclear explosions in the framework of CTBT monitoring. O4.1-636 detailed the scenario of the NPE in 2019. Two NDCs presented their investigations in P4.1-365 and P4.1-613. The NPE 2019 process was delayed due to the postponement of in person meetings of NDCs in 2020 and 2021.

Resilience of the CTBT Monitoring Regime: The COVID-19 Pandemic

The COVID-19 pandemic provided station and network operators as well as the PTS an opportunity to test their readiness to respond to network-side limitations and restrictions. Many lessons have been learned, and many solutions have been, or are being, implemented as a result of the crisis. Among the many lessons learned, the following points were emphasized:

- Remote operation of networks has proven to be workable and can even be efficient. However, for maintenance of stations good local support is essential.
- Improving capabilities for remote maintenance and troubleshooting is crucial for the efficient operation and maintenance of stations.
- Local station support is critical for troubleshooting and repairs. Good training of local support staff is essential and substantially reduces travel requirements.
- It is of major importance to develop and implement reliable means of communication with local operators/ station operators and all parties involved in the operation and maintenance of stations. A more flexible approach to communication on different channels has proven helpful.
- Resilient stations require robustness, including high quality sensors, local data storage capabilities and minimum power requirements.
- Good spare part logistics forms the basis of efficient maintenance, especially when things break. This includes remote spare depots, hot swappable components and thorough pre-testing of spares.
- Preventive maintenance visits and regionalized operation (e.g. in regions of extreme climate) reduce downtime and loss of data availability.
- Remote training, e-learning and troubleshooting videos can be used to overcome travel restrictions.

Propagation of Signals

Better understanding of the propagation media of all relevant signals is crucial for the monitoring system. The propagation

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

medium – the earth for seismic signals, the atmosphere for infrasound and radionuclides, and the ocean for hydroacoustic signals – determines the timing for the signal arrival at the sensors, affects signal strength and, for waveforms, affects signal shape through dispersion. Three Highlight Talks were given at SnT2021, on the properties of the earth (H1-720), the atmosphere (H3-715) and the oceans (H2-716).

Most monitoring agencies rely on fast, distance-dependent, one dimensional (1-D) earth models to calculate seismic event locations quickly and in near real time. The regional seismic travel time (RSTT) software package, presented in P1.2-120, captures the major effects of three dimensional (3-D) crust and upper mantle structure on regional seismic travel times, while still allowing for fast prediction speed (milliseconds). The IDC and many NDCs were very active in testing RSTT and made robust contributions that led to significant improvements, particularly in the uncertainty model (J05). Improvements to the RSTT model enable better travel time estimation for regional signals.

Machine learning efficiently emulates travel time calculations, opening the possibility of using state of the art earth models in the operational system (O3.6-118). O3.5-119 proposed consistent comparisons of seismic location accuracy for 2-D and 3-D velocity models that have been developed using different inversion parameters and ray tracing algorithms. P1.2-369 analysed the difference between the velocity of Rayleigh and Love waves to determine radial anisotropy. O1.2-165 and O1.2-412 analysed P wave data to improve velocity models in the Middle East. Other examples for regional use of RSTT were given in P2.5-086, P2.5-092 and O5.3-072. In P1.2-041, a continental-scale shear wave velocity (Vs) model of the lithosphere was constructed based on the joint analysis of ambient seismic noise and earthquake data. P1.2-368 presented results from drilling crustal rocks and performing active seismic studies.

Invited Talk I03-714 explained that classifying infrasound signals and accurately locating events is complex owing to the inhomogeneity and constantly evolving atmosphere, and the highly changeable environmental conditions at recording sites. Middle atmosphere variability is very important. Long term observations demonstrated gaps of knowledge in the atmospheric models. Noise events in the atmosphere can cause false detection of events. P1.1-627 introduced a hybrid framework to derive prior probability models from waveform modelling.

P1.3-490 discussed 3-D ocean acoustic signal propagation computations for a stratified ocean. P1.3-526 used the combined normal mode–parabolic equation method to carry out modelling of ocean acoustic signal propagation. P1.3-408 emphasized the need for awareness of possible local and temporal changes in sound speed in the ocean with the potential to impact medium to high frequency acoustic propagation.

Atmospheric Transport Modelling

The atmosphere poses a special challenge because of its dynamics and variability. ATM is required to obtain a link between a seismic event and a series of radionuclide detections. Presentation Is4-332 explained the implementation of an ATM system. The current ATM operational system is based on FLEXPART, a Lagrangian particle dispersion model, and uses global meteorological data. Backward simulation is the method of choice if a source is unknown. In special cases where a source location is known, forward modelling is done. Thanks to the optimization of FLEXPART and new ATM servers procured in 2019, a simulation can now be completed within four hours. Is4-332, O2.4-056 and P2.4-637 described the efforts undertaken in the framework of the third ATM Challenge, an international exercise launched in November 2019 that aims to understand the radioxenon background. It is very challenging to run atmospheric models at microscale resolutions over complex terrain. O1.1-596 and P1.1-650 discussed field experiments to evaluate model performance. The differences between forward and backward sensitivities were discussed.

Radionuclide Background

It is vital that nuclear explosion signals can be distinguished from natural and anthropogenic radioactivity in the atmosphere. The global background of xenon isotopes has been found to be higher than what was expected when the Treaty was drafted 25 years ago, mainly due to xenon emissions from medical isotope production. The biggest issue for discriminating nuclear explosion signals from the normal radioactivity background in the atmosphere is the high variability of the background in time and in location (Is7-604). The use of data collected at known facilities may prove useful to remove the effect of these sources.

While isotope ratios in the background are generally different from those associated with a nuclear explosion, uncertainties in the interpretation of IMS measurements remain. Being able to identify the source of civil xenon emissions would increase the robustness of verification. P2.4-211 and P2.4-078 described STAX (Source Term Analysis of Xenon), an experimental network of sensors to detect and quantify emissions of xenon isotopes from medical isotope production and other nuclear facilities. P2.4-206 described measurements to better characterize the radionuclide emissions of a nuclear power reactor. The first observations of environmental ^{125}Xe, ^{127}Xe and ^{129m}Xe were reported in O2.4-138. Similarly, P2.4-607 investigated radioxenon generated by activation sources such as a reactor or strong spallation neutron source. The case studies give evidence that a spallation neutron source can explain past observations of ^{133}Xe and ^{135}Xe. O2.4-510 presented the analysis of the radioxenon detections observed by the new generation SPALAX-NG system near Paris in 2019. The high sensitivity of the system enabled a large amount of multi-isotopic detections, including ^{133}Xe, ^{135}Xe and ^{131m}Xe. The ATM results showed that observed detections came from the main emitter in Fleurus, Belgium, but also from a local producer of radioelements for medical purposes. O2.4-709 presented two statistical methods: parametric and non-parametric, that when applied to ^{133}Xe activity concentration measurements allowed for better understanding of the atmospheric background and anomalous values. Examples of the application of these statistical methods were given in O2.4-406, P2.4-260 and P2.4-261.

Processing of Radionuclide Signals

Radionuclide observations by the IMS are an important part of the CTBT verification regime, as they make it possible to discriminate between conventional and nuclear explosions. In discussion J05, panellists noted that progress in radionuclide processing has been very substantial. It is now possible to use both detections and non-detections to make probability distributions for the original release location and calculate the time and magnitude of the release. Four key challenges were identified: (1) How do we fuse measurements of xenon and aerosols? (2) How do we take the radionuclide background into account? (3) How do we make use of isotopic ratios as a screening tool? and (4) How can we automatically generate a list of associated measurements, the equivalent of waveform association?

The biggest issue for discriminating nuclear explosion signals from the normal radioactivity background in the atmosphere is the high variability of the background in time and in location (Is7-604). Release of activation-generated radioxenon can occasionally interfere with beta–gamma spectroscopy analysis of radioxenon. O3.5-456 used simulations to test the hypothesis that the isotopic activity ratios can be used as a discriminator for activation or fission. Argon-37 is an important indicator of an underground nuclear explosion. P3.5-483 presented a method for assessing ^{37}Ar emissions from nuclear research

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP
SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

reactors looking at an appropriate proxy, such as ^{41}Ar, for which stack release data are available.

Presentations P3.5-507 and O3.5-573 provided an overview of radionuclide analysis methods at the IDC. Potential enhancements of current methods include optimization regression analyses of standard spectra, 3-D fitting and gross counts, and machine learning. P3.5-610 proposed scientific projects to further develop methods for associating multiple samples to the same radionuclide release event and for backtracking to known sources. O3.6-225 and P3.6-509 proposed a model of beta–gamma coincidence radioxenon spectra classification by deep learning (CNN technique) for pre-screening of CTBT-relevant samples. P3.6-516 applied automatic radionuclide detection using deep neural networks to gamma ray detector data. P3.5-245 described the development of an automated process for the fusion of radionuclide and ATM data streams that also provides interactive virtual maps for rapid data interrogation. P3.5-026 described a method to classify particulate radionuclide spectra as "likely normal" or "requires scrutiny" that is entirely ignorant of radionuclide science.

Processing of Seismic, Hydroacoustic and Infrasound Data

The theme of data analysis (including artificial intelligence and machine learning methods) was discussed in the Keynote Address on the opening day (G3), two panel discussions (J05, J08), several Invited Talks (I01-722, I08-723, Is1-353, Is6-454) and many oral and poster presentations, in particular under Topics 3.5 and 3.6. Discussions and presentations focused on using machine learning and artificial intelligence, analysis tools, moving from arrival time parameters to full waveform analysis, improving the understanding of uncertainties, data fusion applications and new pipeline paradigms and methods.

NET-VISA is a physics based generative model of global scale seismology that has recently become part of the operational IDC software. The benefits of NET-VISA were discussed in Invited Talks (I08-723, Is6-454), oral presentation O3.6-400 and poster presentations (P1.1-158, P3.6-651, P4.1-294, P4.1-330). At its inception, NET-VISA was created for the association of seismic events, but it now also supports hydroacoustic (Is2-283) and infrasound (Is3-381, P1.1-158) event data. NET-VISA is expected to become the default phase associator. A new development is the SIG-VISA tool (I08-723, Is2-283). SIG-VISA will consider the full waveforms and add to the analysis the consideration of general waveform shape and coda decay rate, superposition of signals, spatial continuity of travel time residuals, repeatability of waveforms, and more. An important aspect that was repeatedly discussed is the need for physics based models so that explainability remains an important aspect of the interpretation process (panel J08).

The NDC in a box software package is developed, distributed and supported by the PTS. It provides NDCs the capability to perform a variety of functions, including receiving, archiving, processing and analysing data from IMS stations. P3.5-584 demonstrated how Generalized-F Detector (Gen-F) was integrated into an existing NDC Detection and Features eXtraction (DFX) detection framework. P4.1-294 presented the results of testing of the latest release, which contains the NET-VISA associator with SeisComP3.

I01-722 pointed out an important transition in data analysis, which is the move from using arrival times to full waveform exploitation. O3.5-398 used cross-correlation to detect Lg waves to find and locate new seismic events with the help of a sparse temporary seismic network. Is1-353 presented possible new applications for expert technical analysis. P3.5-194 designed a semi-automatic depth estimation tool for events with depths less than 3 km. O1.2-277 proposed two complementary methods to improve signal to noise ratios and automatically identify coherent depth phases. Spot Check Tool (P3.5-355, P3.5-354) is based on waveform cross-correlation and uses information from historical REB events. P3.5-183 attempted to improve the effectiveness of WCC detections using template event metadata and network analysis of corroborating stations. The freely available Coda Calibration Tool (CCT) is a fast and easy Java based platform (P3.5-453) that is three to four times less variable than traditional direct wave estimates.

Automatic identification of repeating seismic events such as aftershocks and mine explosions can help to improve the quality of automatic bulletins and reduce the analyst workload (P2.3-356). The deep neural network tool ArrNet (P3.6-707) can reliably refine the automatically picked arrivals and improve the quality of automatically created event lists and consequently reduce interactive review time.

Unlike array stations, back azimuth estimation for 3-C stations can be unstable (Is6-454). BazNet (P3.6-706) is a deep neural network that makes single-station azimuth predictions accompanied by an uncertainty measure. O3.5-462 argued for the exploitation of all three components of fully 3-C seismic arrays to take advantage of the coherency of the horizontal components. While each piece of information is useful for verification, the full benefit of multi-technology measurements can be further enhanced by data fusion, where disparate sources of data are integrated into a unified and comprehensive event analysis (P3.5-476, P3.5-127, O2.3-130, P2.3-116, P2.3-246, P2.3-366 and P3.1-265). Waveform data are generally contaminated by noise from various sources. P3.6-124 implemented a seismic denoising method that uses a trained deep CNN model. P3.6-615 presented work to develop a new generation of deep neural network to predict the background infrasound noise.

Historical Data and Events, Event Physics and Screening Methods

The 25 years since the Treaty opened for signature have been marked by only a few test explosions. This is a great success, but it also raises a challenge for validation of the tools and methods of the CTBTO monitoring network. As discussed in panel J03, the treasure of historical observations associated with nuclear test explosions is of great value for realistic case studies to validate methods, with the objective of identifying the source of an event that is relevant to Treaty monitoring. These data can also be used to identify challenges in nuclear explosion monitoring and for training and NDC performance exercises. Historical data are needed from as many different regions and geological characteristics as possible. Signals from tests in the atmosphere, underwater and underground should be preserved. Most ongoing efforts focus on seismic data, as historical hydroacoustic and infrasound data are rare and radionuclide data are sparse.

Four aspects should be considered regarding historical data: (1) understanding what data is available and can be retrieved and used, (2) data scanning or scanning/digitizing, (3) metadata and (4) delivery to the broader community. Calibration through known event mechanisms is one of the ways to recover the unknown responses of recorded event sensors. Comparison of records obtained by instruments with known and unknown responses helps to understand the unknown response. O2.5-298 and P2.5-297 described the seismic data catalogue on 47 nuclear tests conducted at the Lop Nor site in China between 1964 and 1996. P2.5-594 and P2.5-499 described the recovery and digitization of seismograms from peaceful nuclear explosions (PNEs) conducted by the Soviet Union in a wide range of geological settings and geographical locations. The amplitude spectral ratios were tested as a discrimination criterion. Historical chemical explosions can also serve as ground truth events for the calibration of regional seismic networks. P2.5-176 described data on large chemical explosions conducted in Kazakhstan during Soviet times. More data on seismic historical events was presented in P2.5-086 and P2.5-089 (Central Asia) and P2.5-181 (Kazakhstan). O2.5-481 presented a literature review on atmospheric radionuclide monitoring, covering 35 nuclear tests conducted between 1964 and 1996. Most of these tests occurred in the atmosphere, but nuclear debris from venting of underground nuclear tests was also observed.

Although the last announced nuclear test of the Democratic People's Republic of Korea was in 2017, work continues on the analysis of these tests. O2.1-275 reported on detections at IMS hydrophone stations of primary and tertiary phases from this test. These appear to be the first detections of this kind at IMS hydrophone stations. P2.1-643 provided a comprehensive overview of how ATM supported the analysis of radionuclide detections from tests in the Democratic People's Republic of Korea. There were matching isotopic ratios and fitting atmospheric conditions for two tests (2006, 2013). Results for two tests were consistent but not conclusive, with detections of ^{133}Xe only (January 2016, 2017). For two other tests (2009 and September 2016), it was not possible to identify potentially related radioxenon detections.

P2.1-123 performed discriminant analyses combining cross-spectral Pg/Lg and Pn/Lg from regional stations. The analysis was able to separate the cavity collapse from the population of nuclear explosions. However, the distinction between the earthquakes and the cavity collapse is ambiguous. P2.1-371 reported on the development of a rapid and automated full seismic source characterization method that correctly identified all announced nuclear tests by the Democratic People's Republic of Korea.

As not all announced underground tests resulted in detected radionuclide signals, it is important to understand the conditions that affect such release of gas and particulates. O2.4-477 presented the results of a series of mesoscale experiments to better understand the interaction between source strength and environmental parameters. Presentation O2.1-208 discussed the implications of the evolution of the cavity after an underground nuclear explosion on the released radioxenon isotopic composition.The presented analysis predicts isotopic ratios that differ from the civilian background more than those predicted by idealized standard models. The refined analysis also predicts reduced quantity of released radioxenon compared with standard models.

The yield of nuclear explosions is not the direct concern of the CTBTO, but it is still of interest for States Signatories to characterize the capabilities of the IMS network. As reported in I01-722, in historical test data it was observed that a lot of the energy was absorbed in crushing rocks in the immediate vicinity of the cavity and in the large ring where anelastic deformations occurred due to the explosion.

A major challenge for the CTBTO is to distinguish between the vast number of detected natural and anthropogenic events and a possible nuclear explosion. Screening methods have been devised for signals from all technologies of the monitoring network. Regarding radionuclide screening, Is7-604 reviewed screening methods for discriminating nuclear explosion signals from the normal radioactivity background in the atmosphere. At times, attributes can be mistaken to yield false positives. P2.3-415 analysed data from the 2018 eruption and collapse sequence of a volcano that are similar to events following nuclear explosions. The initial development of the mb magnitude scale and the mb:Ms criterion for event screening was mainly based on body wave data recorded by standard short period instruments. Today, with both short period and broadband instruments, event screening can be enhanced by understanding variations in mb (P2.3-240).

Information on moment tensors is important for understanding the origin of events. The calculation of moment tensors for weak seismic events is challenging. P1.2-659 reanalysed methods of inversion of amplitudes of P and S waves and inversion of 3-C full waveforms, complemented by first motion polarities. As pointed out in Is1-353, the intersection of earthquake and explosion populations is an important issue when using the focal mechanism as a screening parameter. Depth is a powerful event screening parameter and the main goal of the ParMT application. O1.2-277 characterized uncertainties associated with teleseismic depth determination.

A special subsection focused on results from the analysis of signals captured following the tragic explosion at the Port of Beirut in Lebanon on 4 August 2020. The explosion triggered seismic, acoustic, infrasound and hydroacoustic signals that propagated through the lithosphere, atmosphere and hydrosphere. The presentations merged information from various sensors and technologies of the CTBT monitoring system to estimate the yield of the event. Exact estimates from seismic data are complicated owing to the uncertainty of the coupling of the above ground explosion to seismic waves. Most yield estimates were in the range of 0.5 to 1 kt (O2.1-656, O2.1-228, O2.1-191, P2.1-195, O2.1-290, O2.1-656, P2.1-540, P1.1-401, P1.1-137, P1.1-588 and P1.1-672). The value of combining data from different technologies was shown, for example by largely reducing the location error if one seismic signal is added to the infrasound signals.

P4.1-446 analysed statistics of mostly natural seismicity waveform events processed and analysed over the past 20 years at the IDC and released as the REB on a daily basis since February 2000. A comprehensive reprocessing of the IMS infrasound database was presented in O1.1-389 and P1.1-399. It covers the period from January 2003 to December 2020, with data from up to 53 stations. The IMS hydrophone stations provide low background, high quality data. An analysis of years of data processed using the DTK-PMCC algorithm detector was presented in P1.3-402. P2.5-086 and P2.5-089 reported on the creation of a unified seismic bulletin of Central Asia, using data from 1949–2009. P1.2-155 examined the consistency between the IDC and the International Seismological Centre (ISC) magnitudes for earthquakes. Invited Talk I08-723 suggested considering the use of bulletins that present multiple hypotheses and probabilities. It was noted that the policy of flagging events should be based on realizing the relative costs of false positives and false negatives.

On-Site Inspection

Two Invited Talks focused on the OSI component of the verification regime. OSI was also the subject of Topic 2.2. Presentation I05-727 provided an overview of the remarkable development and interrelationship of OSI capabilities. One key deliverable of work is the first comprehensive draft list of equipment specifications for use during an OSI (Is5-239). P4.4-257 presented the development phases of the OSI technology testing programme. Another key result of work in the past 25 years is the OSI training programme for inspectors, who are nominated by States Signatories. Thus far, three training cycles have been performed. The potential for OSI technical developments and innovations was highlighted in I05-727. These included finalizing the development cycle of existing techniques, development of other techniques such as resonance seismometry, active seismic surveys and drilling, increasing efficiency and efficacy of conducting OSIs, development of capabilities for OSIs in other than standard environmental conditions and in environments other than underground.

Infrastructure is a key enabler to conduct OSIs. Such infrastructure was put in place both at PTS headquarters in Vienna (OSI Operations Support Centre) and at the TeST Centre, which includes the Equipment Storage and Maintenance Facility for OSI equipment, in Seibersdorf, Austria. Another important aspect is field infrastructure. P2.2-220 explained the updated concept and organization of the OSI Operations Support Centre as an ad hoc part of the CTBTO Operations Support Centre (COPC). P2.2-575 addressed the certification, calibration and maintenance of OSI equipment.

Several presentations covered OSI techniques and respective signatures. O2.1-420 described a new method to detect cavities from an underground nuclear explosion that uses the finite-interval spectral power of seismic ambient noise. O3.1-296 studied the potential of time-lapse seismic surveying to identify ground zero by monitoring post-explosion dynamic phenomena. P3.2-691 summarized the layout and design of the next-generation OSI field laboratory with regard to the requirements for measuring OSI-relevant xenon and argon isotopes. Improvements to field capable xenon detection systems for OSI were also reported (P3.2-424, P3.2-518). O3.2-654 presented challenges for the measurement of ^{37}Ar. P2.1-474 discussed an evaluation of the viability of ^{39}Ar as a potential long term indicator. On the processing of imagery, presentations discussed a range of different sensors, both optical and radar (O3.3-117, O3.3-085, P3.3-586, P3.3-132).

Civil and Scientific Applications

Invited Talk I06-721, on the civil and scientific applications of CTBT technologies, was presented by the Director of the IDC Division, who emphasized that the primary purpose of the verification regime is to confirm compliance with the Treaty. However, the Treaty explicitly states that the States Parties may benefit from using IMS data, which are a tremendous asset, for peaceful and scientific purposes. The Preparatory Commission has decided to provide data for two specific civil applications: tsunami warning and radiological and nuclear emergencies. A strong relationship between the scientific and technological community and the CTBTO is a way to ensure that the IMS remains at the forefront of technological innovation and that no nuclear explosion will go undetected (panel J04). Since 2011, the virtual Data Exploitation Centre (vDEC) has allowed scientists and researchers access to IMS data. Scientific and civil applications were discussed in panel J06, as well as Invited Talks I06-719 and I09-742. Many oral and poster presentations, specifically under Topic 5.2, were devoted to possible additional contributions to issues of global concern such as disaster risk mitigation, climate change studies and the United Nations Sustainable Development Goals. Monitoring and understanding volcanic eruptions and earthquakes were dealt with extensively in presentations under Topics 1.1, 1.2, 1.3, 2.3 and 5.2.

There is definitely potential for more civil applications of IMS data beyond tsunami early warning and international cooperation in the event of nuclear and radiological emergencies. For example, the monitoring of recent volcanic eruptions was discussed in P1.1-133, P1.1-588, O1.1-457, P2.3-708, P1.1-253 and P5.2-395. Research progress demonstrates the important role of the IMS network, as well as how it can be enriched by well-designed and optimized regional infrasound networks (P1.1-264) in order to notify civil society and mitigate volcanic hazards (O1.1-536 and P1.1-133). Considering the potential of multidisciplinary approaches is essential (I07-529).

Abbreviations

3-C	three component (seismic station)
AI	artificial intelligence
AS	auxiliary seismic (station)
ATM	atmospheric transport modelling
COPC	CTBTO Operations Support Centre
CTBT	Comprehensive Nuclear-Test-Ban Treaty
CTBTO	Comprehensive Nuclear-Test-Ban Treaty Organization
CYG	CTBTO Youth Group
ECMWF	European Centre for Medium-Range Weather Forecasts
FOR	field of regard
GEM	Group of Eminent Persons
GNSS	global navigation satellite system
GSN	Global Seismological Network
HA	hydroacoustic (station)
HPGe	high purity germanium
IACRNE	Inter-Agency Committee on Radiological and Nuclear Emergencies
IAEA	International Atomic Energy Agency
IDC	International Data Centre Division
IMS	International Monitoring System Division
IS	infrasound (station)
NDC	National Data Centre
NPE	NDC Preparedness Exercise
OSI	On-Site Inspection Division
PMCC	Progressive Multi-Channel Correlation
PSR	possible source region
PS	primary seismic (station)
PTS	Provisional Technical Secretariat
REB	Reviewed Event Bulletin
RN	radionuclide (station)
RSTT	regional seismic travel time
SEL	Standard Event List
SHI	seismic, hydroacoustic and infrasound
SnT	CTBT: Science and Technology conference
TeST Centre	Technology Support and Training Centre
UAV	unmanned aerial vehicle
vDEC	Virtual Data Exploitation Centre
WCC	waveform cross-correlation
WMO	World Meteorological Organization

Contents

1 SnT2021:
A Hybrid Virtual Conference


CTBTO
25
SnT
2021


CTBTO
At the same time, we
congratulate Dr. Robert Floyd on
his election as the new

1. SnT2021: A Hybrid Virtual Conference

SnT2021, the sixth conference in the CTBT: Science and Technology series, was held on 28 June–2 July 2021. The conference was devoted to scientific and technological developments that are important to the CTBTO and the monitoring network, with the main goal of identifying opportunities and methods for improving nuclear test monitoring and verification. Beyond the usual topics of the SnT series, the conference in 2021 had two unique themes: the 25th anniversary of the opening for signature of the CTBT and the COVID-19 pandemic as a resilience test.

The conference was held in the midst of the COVID-19 global pandemic. Travel restrictions and limitations on physical attendance necessitated a change in format. To preserve some continuity with the approach of previous conferences, the opening day was a hybrid event, combining a limited in-person audience of about 200 people in the Hofburg Palace in Vienna with a virtual audience around the world. Even on the first day, most participation was online, with many presenters and more than 1000 attendees participating off-site. The remainder of the conference was purely virtual, with the Vienna International Centre (VIC) premises serving as a hub to run the conference sessions.

The SnT2021 conference was the largest ever, with more than 1600 participants. A total of 1546 attendees registered for the full SnT2021 week. In all, 89 oral presentations were given, and slide and video files to 365 posters were uploaded. Statistics on various conference aspects are provided in Appendix 2 of this report.

The posters were uploaded ahead of the conference, giving them an extended exposure. Presenters had the opportunity to participate in 10 round table sessions, each comprising 15 to 25 presenters who were given two minutes to present the highlights of their poster, followed by time for questions and discussion. These round tables attracted a lot of attention, with some enjoying the participation of more than 250 online attendees. Such exposure of posters is definitely higher than what was common for the 'normal' physical presence conferences of the past. While there are certainly advantages to face-to-face interaction, video rooms and chats enabled attendees to interact with presenters.

The virtual platform of the conference was called vSnT2021 and supported by Superevent B.V. It was available to all registered users on web browsers as well as on mobile devices. During the conference week, an unprecedented number of 1458 participants registered and logged onto this platform. Conference sessions were held in Webex virtual rooms and streamed to live "stages" supported by vSnT2021. The technical reliability of the platform was high, and there were no major problems during the conference.

While the technical arrangements for the virtual conference were very different from past conferences, the programme largely followed the example of previous successful SnT conferences. For much of the time, three live stages were streamed in parallel, and online participants could easily switch from one session to another. Sessions were run from the VIC, mostly by PTS staff. Every session had a small technical support team of three to four people and a content team comprising the session convener and a Q&A coordinator. All panel discussions consisted of off-site online panellists. For some panels, the moderator was also off-site. In such cases, the PTS convener who was physically present in the session room at the VIC provided support to ensure the smooth conduct of the discussion.

All presenters were strongly encouraged to upload recordings of their presentations before the conference. These files were uploaded to the Indico database that served the conference. For oral presentations, either the recordings or live presentations

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

were used during the sessions. The transition between live and recorded content was handled by the Webex PTS teams and ran smoothly, with almost no technical problems. Sessions were recorded and made available as YouTube videos. Appendix 1 of this report includes the conference programme, with the appropriate YouTube links to sessions.

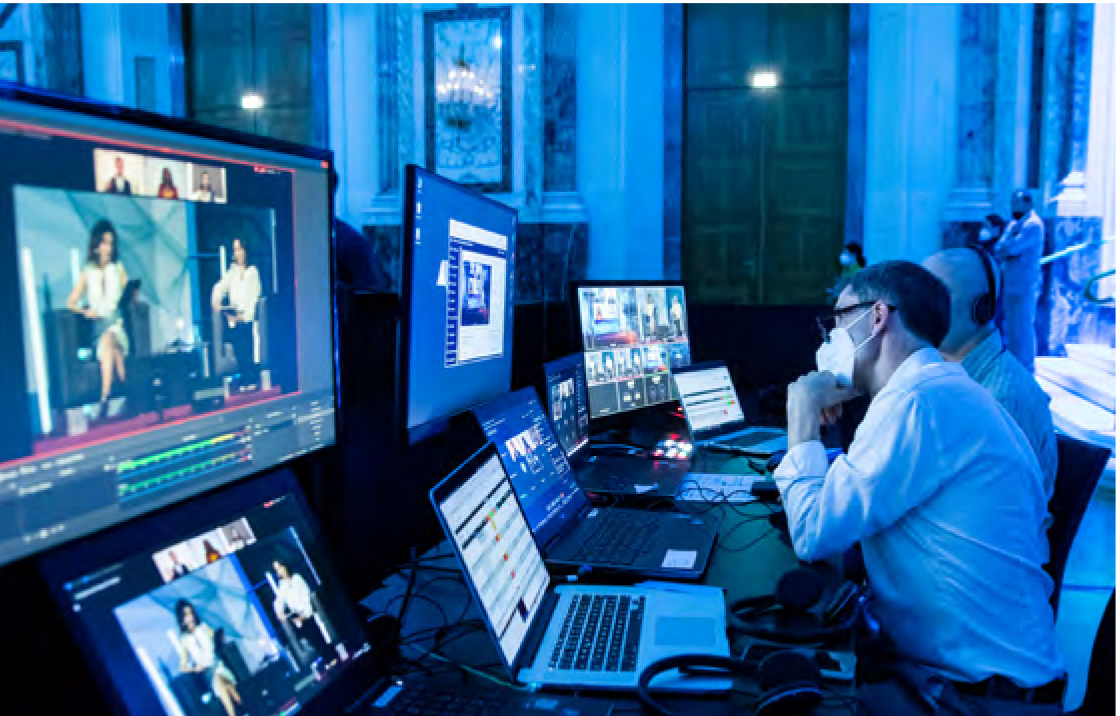
The uploaded files of oral and poster presentations constitute an invaluable resource. In this report, the designations that appear in the summaries of the talks, panel discussions and presentations are hyperlinked to these uploaded files. Especially for poster presentations, this is a unique modality to retain knowledge that was not available in previous physical conferences. This element of the virtual conference format is very important for the preservation of conference material, and it is strongly recommended that it be retained in future SnT conferences, regardless of format.

The relative number of actual presentations delivered compared with the number of submitted and accepted abstracts was approximately 80 per cent, which is higher in comparison with previous SnT conferences. For posters, only those for which the authors uploaded files are considered as being presented and included in this report. This level of compliance is remarkable, especially given the fact that the format of the conference was announced only in February, months after the deadline for the submission of abstracts. An important element of this success was the frequent issuance of newsletters in the two months before the conference with instructions on how to prepare and upload presentations. The dedication of PTS staff in supporting conference participants is highly appreciated.

While it is a fervent hope that future SnT conferences will be held in person, there are important aspects of the virtual conference format that are beneficial and worth continuing. Online presentations and attendance can enable those who cannot travel to participate. This enriches the opportunities for unique presentations at the conference. Early uploading of poster files and poster round tables resulted in much longer and wider exposure of posters. There is also an improved level of documentation accompanying the presentations with uploaded poster and slide files and recorded talks and discussions. These elements should be retained in future conferences.

2 Opening Day at the Hofburg Palace, Vienna


CTBTO
SnT
2021
25
SnT
2021



2. Opening Day at the Hofburg Palace, Vienna

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) opened for signature 25 years ago. Its tested and proven verification regime, which is the result of an investment of more than US$1 billion, is nearly complete. While the global norm against nuclear testing is well established, as evidenced by recent ratifications by Cuba and the Comoros in 2021, the Treaty is not yet legally and universally binding. This seeming paradox requires both innovative approaches to achieve the long-sought political breakthrough of entry into force, as well as scientific and technological advances to sustain, improve and maintain the valuable contributions of the International Monitoring System (IMS).

To mark this important anniversary, the High Level Opening of the CTBT: Science and Technology 2021 conference (SnT2021):

- Reaffirmed the achievements of the CTBT in obtaining acceptance of a global norm against nuclear testing and the technical advances of its verification regime and technologies;
- Outlined the essential role of the CTBT in achieving a world free of nuclear weapons; and
- Took a journey across time, from the origin of the Treaty in 1996, to its multidisciplinary present and towards a vision for the future through the lens of space travellers, scientists and the next generation of leaders.

2.1. Opening Message by Executive Secretary Lassina Zerbo

Excellencies,
Ladies and Gentlemen,

It a great pleasure to welcome you to the CTBT: Science and Technology 2021 conference – the sixth such conference to be held in the SnT conference series.

I am delighted to see so many good friends and esteemed colleagues in the audience this morning. Yet the excitement and enthusiasm that would flow through the halls of the Hofburg Palace from the more than 1000 attendees at previous SnT conferences is dearly missed.

The COVID-19 pandemic has changed our lives and affected our livelihoods in so many ways. The hybrid nature of SnT2021 is just another reminder that we are still locked in battle with this fearsome disease. And while science, technology and human ingenuity have provided us with hope of a return to a new normal, it is far too early to celebrate in victory or let our guard down.

One important lesson that the pandemic has taught us is that we must be adaptive and innovative to operate in today's world. This is how we have approached the planning of SnT2021.

When it became clear that a traditional in-person conference at the Hofburg was impossible, we set out to design a hybrid event that would allow us to still deliver on SnT goals and objectives. It is my view that we have indeed delivered a virtual conference experience that goes far beyond expectations.

For this, Provisional Technical Secretariat (PTS) staff who have worked tirelessly over the course of many, many months to make this hybrid SnT2021 a reality have my deepest gratitude. Please also join me in thanking Elazar (Eli) Sarid, SnT Programme Coordinator, as well as the members of the Scientific Programme Committee and the Scientific Programme Group.

Planning and organizing a virtual format for a conference of this scale has been a daunting task. The resolve of the staff members who have worked around the clock to overcome these pressing challenges so that all SnT2021 participants can enjoy a rich and rewarding conference experience is to be commended.

Let me also thank the speakers, presenters, panellists and e-poster contributors for their efforts to adapt to the hybrid format. Your efforts to produce and present content in a virtual environment are very well appreciated.

Programmatic Highlights

Except for today's High Level Opening hybrid events, the entire SnT programme will be convened through the Virtual SnT2021 Portal (vSnT2021 Portal). This is simply a reflection of the current circumstances we face today.

Worth noting is that more than 1600 participants registered to attend the conference. The oral presentation sessions and e-posters are populated from approximately 600 abstract submissions. In addition, SnT2021 features a series of Highlight and Invited Talks.

The conference has two important themes that are unique for this year: the 25th anniversary of the opening for signature of the CTBT, and the COVID-19 pandemic. The 25th anniversary theme includes a series of Invited Talks and panels that address various aspects of developments over the past 25 years, as well as the challenges and prospects for the Treaty in the future.

The transboundary nature of the COVID-19 pandemic produced a global resilience test. This experience and the lessons that can be learned are discussed in a dedicated panel and a series of oral presentations distributed over several sessions.

Overall, the different mechanisms for virtual interaction and engagement through the vSnT2021 Portal are impressive and unique. Please do take the time to explore the vSnT2021 Portal and benefit from its rich content and remarkable functionality.

Resiliency in a Challenging World

The broader implications of the COVID-19 pandemic have already been noted. And we must also recall the enormous toll that the disease has taken on society as a whole in terms of human loss and suffering, as well as in social and economic turmoil.

We have had to learn how to cope with the new realities, and to maintain operations and fulfil obligations. Lockdowns, travel restrictions and other measures aimed at mitigating the damage caused by the virus have created chaos and uncertainty. This has forced us to make difficult choices among less-than-ideal alternatives.

At the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), we found ourselves in a similar situation. However, it brings me great pride to point to the measures that we took early in the pandemic to protect the health and well-being of our staff, while ensuring continuous functioning of the organization.

These successes could only be achieved with a worldwide "all hands on deck" approach. This has involved exceptional efforts by PTS staff, station operators, National Data Centres (NDCs), analysts and logistics and maintenance support teams around the world. Your commitment to keeping the ship afloat in these trying times has been unshakable.

As we continue to step back from the abyss and get to work building back better from this devastating global shock, let us not forget to take heed of the important lessons at hand:

- Addressing 21st century transboundary challenges requires us to lean on each other more, not less.
- It requires more sustained international cooperation and collaboration, not less.
- It requires more strong, credible and capable institutions, not fewer.
- It requires more resiliency and innovation in our solutions to global challenges, not less.
- It requires more focus on science-driven policy solutions for the global good, not less.

These are the ideals and objectives that produced the CTBT in the first place, and it is adherence to these ideals and objectives that will bring the Treaty across the finish line.

Milestones Along the Way

Looking back at my time with organization, both as Director of the International Data Centre (IDC), and as Executive Secretary for these past eight years, there are many shared achievements that can be highlighted.

The first nuclear test by the Democratic People's Republic of Korea in 2006 provided an early real-world test for the IMS. We may take for granted the capabilities of the verification regime today, but let us not forget that at the time the IMS was less than 60 per cent complete. IDC processing software and procedures were still under development.

While many estimates put the test in the sub-kiloton range, the event was detected by 22 stations and provided an uncertainty ellipse of 880 square kilometres. This is well within the required location accuracy needed to launch an on-site inspection (OSI) in accordance with the Treaty, once in force.

Another shared success was the agreement to provide technical assistance and data to tsunami warning centres to help tsunami early warning efforts in the aftermath of the devastating 2004 Indian Ocean tsunami. The vast potential for civil and scientific applications of monitoring data is now well recognized by the international scientific community, and this agreement was a vital first step. Today, 18 such agreements with tsunami prone countries exist.

Another tragic example of the utility of the system outside of the core mandate of nuclear test monitoring was the Great East Japan earthquake, tsunami and Fukushima nuclear power plant accident in March 2011. Of note was the incredible sensitivity of the radionuclide network, which was able to track the dispersion of small amounts of radionuclides following the power plant accident. This also led to increased collaboration with the International Atomic Energy Agency (IAEA) as our organization became a member of the Inter-Agency Committee on Radiological and Nuclear Emergencies.

On 15 November 2017, when the submarine *ARA San Juan* went missing, the CTBTO provided timely information from two hydroacoustic stations to authorities in Argentina to support search efforts. The *ARA San Juan* was eventually found less than 20 km from the source location of the hydroacoustic anomaly detected by CTBTO.

Recognition of the value of IMS data for the broader international scientific community was one of the driving factors in convening the first CTBT: Science and Technology conference in 2011. As the scientific community learns more about the "noise" in the data, we can better filter for the signals that could be associated with a nuclear explosion. Exploring the scientific applications of the CTBT verification infrastructure is a win-win situation.

This also inspired us to launch the virtual Data Exploitation Centre (vDEC), which provides scientists and researchers at

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

various academic and scientific institutions worldwide with access to requisite data to conduct research and to publish new findings on a wide array of disciplines.

It should be noted that the European Union will offer an award for the best contribution dealing with these topics on Friday. More details can be found on the vSnT2021 Portal.

Since being appointed Executive Secretary in 2013, two key objectives have always been at the top of my agenda: promoting the Treaty's entry into force and universalization and strengthening the organization while building up its verification regime.

We have been making great strides in building up the verification regime. Nearly 90 per cent of all IMS facilities have been certified, and as more stations come online, we will improve the coverage and resilience of the network. Significant progress has been achieved in fulfilling the requirements of the IDC progressive commissioning plan. And our OSI capabilities continue to measurably improve.

Specific examples that are worth highlighting in these areas include advancing through the validation and acceptance test plan; simulating an almost full scale OSI through the 2014 Integrated Field Exercise; and establishing the Technology Support and Training (TeST) Centre, a hub for storage, maintenance and testing plus state of the art training facility that contributes to all elements of the verification regime.

On the universalization side, we have made important advancements with an additional 13 ratifications and 2 signatures only in the past 8 years. There are now 185 States Signatories to the CTBT, out of which 170 have already ratified. As a result of recent efforts, more ratifications should soon be forthcoming. This is a strong record of achievement for any treaty, particularly one dealing with the complex issues of nuclear disarmament and non-proliferation.

One crucial aspect to emphasize is the role of the next generation in advancing the global peace and security agenda. The CTBTO Youth Group (CYG) was established in 2016 with this point in mind. To date, the group comprises more than 1000 members from all over the world, who are working hard to shape the future in their own vision. This vision includes the entry into force of the CTBT. All students and young professionals should be encouraged to join this growing force for change.

The Group of Eminent Persons (GEM) is another initiative aimed at enhancing high level engagement with all States that have not signed or ratified the Treaty. As distinguished and influential voices in the realm of international security affairs, GEM has contributed to a steady increase in signatures and ratifications since its founding in 2013.

All in all, international support for the CTBT remains near universal. My successor surely will continue to draw additional States into the CTBT family, moving us even further towards full universalization.

Looking Towards the Future

As we look out on the horizon and try to forecast the geopolitical trends that will impact the future of the CTBT and the organization, there may be temptation to dwell on the political and legal challenges that have precluded full implementation of the Treaty.

Rather, let us take a broader perspective. The adoption of the CTBT at the General Assembly was decades in the making. The Treaty came into being despite countervailing pressures in the international security environment that persisted for many years. It is the culmination of countless lifetimes and livelihoods spent pushing for a verifiable end to nuclear explosive testing for all time.

While we may continue to face strong headwinds in crossing the finish line of entry into force, let us not forget to recognize that the long term trend has been nothing but positive. The international security environment will always ebb and flow, but the CTBTO mission of ushering in a world without nuclear tests remains the same.

As we see it, there are many reasons for optimism. Despite the political and legal challenges of entry into force, the CTBT continues to be a shining example of international technical cooperation as a driving force in global arms control efforts.

It exemplifies the importance of science diplomacy in advancing the international peace and security agenda. It is more apparent than ever before that science-driven policy is the only way to create a more peaceful and prosperous world.

Bringing the CTBT into force is one such measure to do so. For that, all of you can help. Whether contributing to the advancement of the science and technology of nuclear test monitoring, conducting research and analysis that will enhance the dialogue and discourse on the Treaty, participating in policy making, or advocating it in civil society, we are all working towards the same goal.

Glancing to the future of the CTBT and this organization, I am fully convinced that this future is in your good hands.

Thank you.

2.2. Session 1

G1 – Ceremonial Opening and Political Remarks

In his opening remarks, Executive Secretary Lassina Zerbo emphasized that the CTBT continues to be an "example of international technical cooperation as a driving force in global arms control efforts." The CTBT highlights the importance of science diplomacy in advancing the international peace and security agenda. The Executive Secretary also noted, "It is more apparent than ever before that science-driven policy is the only way to create a more peaceful and prosperous world."

In February 2021, Cuba and the Comoros ratified the CTBT. Via video messages, the Foreign Ministers of Cuba and the Comoros highlighted the recent capacity building efforts in the developing world and the respective scientific benefits of the Treaty, which led both countries to sign and ratify the CTBT in its 25th anniversary year. Foreign Minister Bruno Rodríguez Parrilla of Cuba stressed that "the prohibition and ceasing of nuclear tests of any kind is crucial to achieving the goal of the complete elimination of nuclear weapons." Foreign Minister Dhoihir Dhoulkamal of the Comoros appealed to the international community to boost its efforts towards universal adoption of the CTBT as "this essential instrument of trust and stability." He added that "the political will and commitment of all national actors to this end is the cornerstone that will turn this ideal into reality."

Ghada Fathi Waly, Director-General of the United Nations Office at Vienna (UNOV), delivered a statement on behalf of United Nations Secretary-General António Guterres. In his message, the Secretary-General praised the achievement of the IMS in using modern technologies to build trust among countries, stressing that "the system has become an indispensable tool in the global disarmament and non-proliferation regime, and its associated technologies also have vital civilian applications." The

Secretary-General also noted, "The CTBTO is one of the pioneers in using modern technologies. Its cutting edge IMS helps to build trust among States about compliance with the Treaty."

Peter Launsky-Tieffenthal, Secretary General of the Foreign Ministry of Austria, presented a message from the host country on behalf of Foreign Minister Alexander Schallenberg, stating that the CTBTO was a true flagship bringing the best of science and diplomacy together into a highly effective organization.

Rafael Grossi, Director General of the IAEA, emphasized the CTBT's essential place among international non-proliferation treaties, providing certainty that nuclear tests are not taking place. He stated that "the CTBT is not a treaty of the past but a treaty of the future" and is an essential element of "the nuclear non-proliferation architecture". He also noted that SnT2021 is spreading the word about how the IMS is maintaining a degree of awareness about the elaborate verification system of the Treaty, whilst at the same time making the world almost forget that the CTBT has not yet entered into force.

Li Yong, Director General of the United Nations Industrial Development Organization (UNIDO), said the pandemic was a call for solidarity and closer international cooperation, requiring multilateral solutions and the best use of advanced technology, science and innovation.

Stephan Klement, European Union Ambassador and Head of Delegation to the International Organisations in Vienna, delivered a statement on behalf of the High Representative and Vice President of the European Union, Josep Borrell, in which he stressed the value of the CTBT, not only for nuclear non-proliferation but also for a range of civil and scientific applications, including the study of climate change, oceans and ecosystems, seismic activity and the prediction of tsunamis.

G2 – Facilitated Dialogue on CTBT@25 Years. Evolution of the CTBT, the Organization and Its Technologies and CTBT's Model Function of Inclusion and Science Cooperation

In a facilitated dialogue session, senior officials involved in the historic negotiations of the CTBT text during the Conference on Disarmament reflected on their experiences and the challenges, but especially on the remarkable achievement of agreeing on the Treaty text. Ambassador Jaap Ramaker of the Netherlands, who chaired the CTBT negotiations in 1996, noted that exactly 25 years ago, on 28 June 1996, he introduced a final text that would become – with one minor change – the text of the Treaty. Ambassador Grigory Berdennikov, who led the delegation of the Russian Federation at that time, recounted how the unique entry into force clause in the Treaty was considered "the only workable marriage between all nuclear [weapons] States and those States with nuclear capabilities." This solution aimed to avoid delaying entry into force through mutual dependence, which worked in large part, with the exception of the remaining eight countries that are still holding out.

Jenifer Mackby, Senior Fellow at the Federation of American Scientists, provided insight on how the Group of Scientific Experts (GSE), comprised of a global set of governmental science advisers, devised an elaborate seismic monitoring system over the course of 20 years. Established in 1976, the GSE conducted three international technical tests and established the concept for an international seismic monitoring system. As late as 1995, the GSE demonstrated in the third and last technical test that it was possible, using technology that was then considered state of the art, to send real time data from different seismic monitoring stations to an international data centre, hence showing that the nuclear test ban that was concurrently being negotiated could indeed be verified.

Anne Strømmen Lycke, Chief Executive Officer of NORSAR, reflected on the important role of NORSAR scientists in GSE discussions since 1976 and during the Treaty negotiations. Lycke noted that most of the thorough scientific work done ahead of the negotiations could "more or less" be used as a blueprint for the Treaty text on verification. She remarked that the CTBT negotiation and the work of the GSE was a fabulous victory for science and diplomacy.

Other distinguished high level speakers also shared their ideas and reflections on the role and important contribution of the CTBT. Lord Des Browne of Ladyton, former United Kingdom Secretary for Defence and member of GEM, focused on the present importance of the CTBT as a confidence building measure should a nuclear escalation crisis arise. He noted that along with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the CTBT is one of the last two almost-universal nuclear arms control treaties. Ernest Moniz, Vice Chair of the Nuclear Threat Initiative (NTI) and former United States Secretary of Energy, focused on the remarkable verification architecture of the IMS and the International Data Centre (IDC), which has demonstrated the technical verifiability of the Treaty during the six announced nuclear tests by the Democratic People's Republic of Korea. Moniz noted that the "IMS has proven to be a remarkably robust system" and "is an incredible scientific achievement". Tarja Halonen, former Finnish President and member of GEM, highlighted that strengthening arms control requires strong multilateral institutions, as well as building trust and cooperation between States. Halonen has championed a more comprehensive approach to security and stressed, "It's necessary to ensure full and meaningful participation of women in all policy making, planning and implementation regarding peace security and disarmament." Noting the recent CTBT ratifications by Cuba and the Comoros, former United Nations Secretary-General Ban Ki-moon remarked that every ratification moves us one step forward down the right path and brings us closer to ending nuclear testing and to building a better and more secure world. He stressed that the CTBT is critical to global peace and our overall security.

The dialogue concluded with remarks from CYG members from Kenya, Madagascar and Pakistan. Their high level participation underlined a strong youth engagement theme that continued into the lunch break with a dialogue between the Executive Secretary and other CYG members on the evolution of the SnT conference series.

2.3. Session 2

G3 – Keynote Address by Dimitri Kusnezov Artificial Intelligence: What, Why and How It Could Transform Our Missions

Speaker: Dimitri Kusnezov[1]

[1]*Deputy Under Secretary for AI and Technology at the US Department of Energy*

Artificial Intelligence (AI) has the potential to revolutionize the very ways we live our lives and make our world more sustainable and equitable. Today's AI based methods, which are still nascent and narrowly applied, are already providing means to innovate and impact everything including science, environment, energy, health, and climate. AI impacts the U.S. Department of Energy (DOE) across all missions, businesses, and operations, and has become central to accelerating scientific discovery and the development of transformational new technologies. The DOE, like the CTBTO PrepCom, needs trustworthy AI systems that are accurate with high confidence and proven to be unbiased and reliable. Working in collaboration with global partners, DOE – the largest sponsor of physical sciences in the United States and largest generator of Nobel-prize winning scientists in the world – is driving high-risk research and development to advance the science of AI to create AI-enabled technologies that fulfill these requirements.

This presentation will highlight a number of examples of AI in practice at DOE today, emerging areas of interest, and insights on opportunities presented by AI for the CTBTO PrepCom, drawing on decades of experience developing cutting-edge science and technology capabilities to deter and detect nuclear explosive tests.

Artificial intelligence (AI) has become a pervasive part of our lives, and it is difficult to perceive the tremendous transformations that are at work today, as it was with the early development of technologies in Silicon Valley, California, that led to their extensive use today by hundreds of millions of people. In his current position at the United States Department of Energy, the presenter deals with a variety of missions that the department is tasked with, including many where the questions being asked do not have a ready answer. Predictions are part of daily life, and the department is often asked to intervene to answer difficult questions, not only about scientific issues but also questions with a societal impact.

In his Keynote Address, Dimitri Kusnezov viewed questions about artificial intelligence through the prism of science and knowledge creation that started with the scientific revolution that took place in Europe, between the end of 16th and the beginning of the 18th centuries. This includes the two pillars of observation: experiments and empiricism on one hand, and deduction, modelling and theory on the other hand. The latter has seen tremendous advances since the 1940s, when transistors and computers were designed to solve equations. Supercomputers can now perform 10^{18} operations per second. The computer architectures are tuned to running models and not to the huge amount of data that are acquired nowadays. Comparing the massive number of results coming out of the computers running complex models to these data is extremely challenging. Computers have empowered us to solve problems that until the 1950s were handled with pen and paper calculations. The complexity of the world's models has increased, and computers have helped piece them together much beyond human capabilities.

AI is a category of empowering ideas that are still nascent, although some approaches may have already existed for a long time. From an engineering point of view, the components of an AI system can be clearly identified and listed as data acquisition through sensors, learning from data, deciding based on knowledge acquired, human interface and automation. AI systems live in rich data environments. From a scientific point of view, it is debatable whether AI deals with concepts such as cognition, consciousness and intelligence, but these are interesting, almost philosophical questions to consider.

From a practical point of view, AI attempts to simulate the human brain in its multitasking, learning, adaptive abilities and contextualizing, with fault tolerant and low energy consumption features. Many narrowly defined objectives are already implemented and touch on people's daily lives. This includes instantaneous speech translation, credit card fraud detection, navigation and gaming. The basic approach is to create a model from data. The system is trained on vast amounts of data to obtain a model. Inference is the next step of using that model and applying it on more data. Deep learning is a subset of AI that is motivated by simulating the brain, although it is not a model of the brain. Many applications are already using unsupervised deep learning for such mundane applications as suggesting to customers the next movies to be watched on a streaming service.

AI is not owned by one single entity, and the private sector is its primary driving force. Therefore, partnerships and team building are very important to its development. Governments are not the leaders, as was similarly the case for supercomputer development.

Much like advances in computer technology were the accelerator of the second pillar of knowledge acquisition, AI is an accelerator for the first pillar of empirical knowledge acquisition from big data. Besides everyday applications, more technologically interesting systems are being developed, such as OpenAI, which allows people to converse with simulated historical or fictional characters, write computer code to solve a problem, complete images from a fragment or write music from a few initial notes. The Chinese system Wu Dao 2.0 can generate prose in English or Chinese and has created a virtual student who can attend school and learn new things.

The two pillars of the scientific era, the empirical and the theoretical approach, are converging. AI is becoming a super enabler of the empirical branch, while fast computers are empowering the theoretical branch. They are becoming more interdependent and intertwined. Simulations are brought into data, and data into simulations. There are caveats to its use currently because of its fragility and relative insecurity, as AI can be used in nefarious ways.

The AI transformation is in its infancy, and it is fundamental not only to the ways we approach knowledge creation but also to many aspects of our daily lives. It can provide answers to difficult questions and will certainly have a societal impact.

2.4 Panel Discussion

G4 – Space Science and Technology for Global Sustainable Development, Peace and Security

The panel discussion on space science and technology for global sustainable development, peace and security was chaired by Simonetta di Pippo, Director of the United Nations Office for Outer Space Affairs (UNOOSA), and included a keynote address by European Space Agency (ESA) Director General Josef Aschbacher. Other speakers included two former astronauts: Science and Technology Minister Marcos Pontes of Brazil and the first Western European in space, Jean Loup Chrétien of France.

The discussion highlighted the critical role of space assets and their potential for addressing local and national challenges, including disaster risk reduction, and for building a better tomorrow. Aschbacher highlighted some commonalities between the ESA and the CTBTO, noting that both organizations are enhancing transparency and constantly monitoring our planet, albeit using different technologies. UNOOSA Director di Pippo also noted synergies and common endeavours between the CTBTO and UNOOSA. Capacity building activities, education, inter-operability and access to data, and the power of science to contribute to sustainable development and security goals were key themes throughout the discussion.

2.5 CTBTO Youth Group Engagement at SnT2021

At SnT2021, the CTBTO Youth Group was prominently represented through a number of diverse engagements. A common theme was advancing the role of young people in international security, raising awareness of the CTBTO and its verification regime, promoting entry into force and universalization of the Treaty, and outreach to the larger public.

The hybrid format of the conference created new opportunities for CYG members to launch initiatives and present their work in a variety of innovative formats. Twenty-eight CYG members were selected as presenters, and 21 members were featured as poster authors. Of the more than 1600 registered attendees, a significant proportion were youth participants who watched the conference on the vSnT2021 Portal. For example, over 300 virtual viewers attended CYG events during the opening day of SnT2021, in addition to an in-person audience at the Hofburg Palace, Vienna.

The CYG featured prominently in the SnT2021 programme. Three of its members, from Pakistan, Kenya and Madagascar, participated in the facilitated dialogue on "CTBT@25 Years. Evolution of the CTBT, the Organization and Its Technologies and CTBT's Model Function of Inclusion and Science Cooperation" during the high level opening of the conference. In addition, CYG Coordination Team members Cristopher Cruz (USA) and Kseniya Pirnavskaia (Russian Federation) held a dialogue on the evolution of the SnT conferences with Executive Secretary Lassina Zerbo (SE1). CYG members Yeseul Woo (Republic of Korea) and Alan Juarez (Mexico) held significant roles during the panel discussion "Securing a Nuclear-Test-Free World for Youth and the Next Generations", which was jointly organized by the European Union and the CTBTO. The discussion brought together young people and seasoned ambassadors to discuss how youth participation is critical to achieving international non-proliferation goals and the entry into force of the CTBT.

CYG members had an exclusive introductory briefing session on 25 June with PTS representatives, including Conference Organizer Elazar Sarid, Sabine Bauer of the Office of the Executive Secretary and CYG Coordinator Maria Chepurina. The CYG also organized fireside chats with prominent CTBT contributors that were hosted by members of the CYG Task Force. Anton Khlopkov, Director of the Center for Energy and Security Studies and nuclear non-proliferation expert; Tracey Rogers, author of a seminal study on blue whale populations using hydroacoustic data from the CTBTO verification regime; and Zainab Azim, the youngest astronaut to fly with Virgin Galactic, participated in the discussions.

CYG members contributed to the International Gender Champions panel to discuss the role of youth in achieving gender parity in the disarmament field. They were also offered a unique opportunity to interact with OSI experts as part of the OSI Educational Initiative for Young Professionals with a Technical Background (see below).

The CYG partnered with GEM for a unique virtual mentoring session, where young people had an opportunity to interact with leaders in nuclear non-proliferation and seek career advice, ask personal questions and learn about prospects for the future of the CTBT, all under Chatham House rules. The event created an accessible platform for young people to interact with industry professionals, setting the precedent for more exclusive events between the groups and encouraging the next generation to stay the course for nuclear disarmament and non-proliferation advocacy.

The newly created CYG Citizen Journalism Academy provided social media coverage of SnT2021 events. Youth Group members attended a four-week training course with social media and journalism experts from Atomic Reporters to learn how to provide high quality coverage of conference events. Of the 80 workshop participants, 25 were selected as Citizen Journalism Fellows and given exclusive access to conference organizers and participants to produce video interviews, written coverage and social media products. The five best Citizen Journalism Fellows were awarded the opportunity to attend an in-person CYG event in Geneva.

In 2021, CYG reached a milestone of 1000 members. Looking ahead, it will continue to pursue its goal of expanding membership and creating new opportunities for students and young professionals. The CYG Task Force encourages all SnT2021 participants to spread the word about the opportunities available to CYG members and encourage experts under 35 to join: https://youthgroup.ctbto.org/.

SE3 – OSI Educational Initiative for Young Professionals with a Technical Background: Presenting Outcomes

The OSI Division, in partnership with the CYG Task Force and the National Research Nuclear University – Moscow Engineering Physics Institute (NRNU–MEPhI) in the Russian Federation, conducted the side event "OSI Educational Initiative for Young Professionals with a Technical Background: Presenting Outcomes" on the margins of the conference.

For the opening segment, the esteemed guests CTBTO Executive Secretary Lassina Zerbo; Ambassador Mikhail Ulyanov, Permanent Representative of the Russian Federation to the International Organizations in Vienna; and Aleksey Astakhov, Deputy Commander of the Special Monitoring Service at the Ministry of Defense of the Russian Federation, addressed the participants.

The event featured nearly 30 active participants and was also streamed live. It concluded a month-long research project focusing on different aspects of operationalization of the OSI mechanism of the CTBT. NRNU-MEPhI students were divided into four working groups and assigned case studies prepared by staff of the OSI Division. A number of OSI-specific topics were included, such as improvement of xenon separation, approaches to preserve the confidentiality and integrity of inspection data, installation and operation of airborne optical sensors, and ways to support the progress of an OSI through rule-based fuzzy logic. Through this exercise, aspiring scientists had an opportunity to offer fresh insight on how to address actual technical questions the PTS deals with on a daily basis. Participants presented their solutions to an international panel of OSI experts who provided feedback.

This project is a continuation of the time-tested partnership between the PTS and NRNU-MEPhI, the leading nuclear research university in the Russian Federation. All participants expressed interest in capitalizing on the success of this event to further develop and potentially expand this initiative.

European Union–CTBTO Panel Discussion G5 – Securing a Nuclear-Test-Free World for Youth and the Next Generations

To round off the opening day, the European Union and the CTBTO co-organized a panel discussion that highlighted the importance of the Treaty for future generations.

The distinguished panel comprised:

- Ambassador Stephan Klement, Head of the Delegation of the European Union to the International Organisations in Vienna;
- Ambassador Leena Al-Hadid, Permanent Representative of Jordan to the United Nations and other International Organizations in Vienna;
- Ambassador Marjolijn Van Deelen, European Union Special Envoy on Disarmament and Non-Proliferation;
- Yeseul Woo (Republic of Korea), member of CTBTO Youth Group;
- Alan Juarez (Mexico), member of CTBTO Youth Group.

Maria Chepurina of the PTS moderated the discussion.

The panel focused on youth engagement as part of efforts to promote the universalization of the CTBT and its entry into force, which is a political imperative for the European Union and a good example of work to strengthen the rules-based international system. The panel also examined how the European Union, as a staunch supporter of the CTBT and its organization, has contributed to CTBTO efforts to engage youth, and more broadly in the areas of capacity building. The panellists discussed the status of youth engagement with respect to the Treaty, noting that the main requests and suggestions from youth to policy makers focused on advancing entry into force and thus moving a step closer to a world without nuclear weapons.

During the closing session, the European Union Star Award was announced (see Section 6.6 of this report). The award was established in 2013 by the Delegation of the European Union to the International Organisations in Vienna as an acknowledgement of the new scientific and technological developments relevant to the CTBT.


SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE
28 JUNE - 2 JULY
VIENNA, AUSTRIA

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE
28 JUNE – 2 JULY

SnT
2021


3 25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks

3. 25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks

3.1. I01-722 – Challenges and Achievements of Monitoring for Nuclear Test Explosions in the Context of the CTBT

Speaker: Paul G. Richards[1]
[1]*Lamont-Doherty Earth Observatory of Columbia University, New York, NY, USA*
Corresponding Author: richards@ldeo.columbia.edu
Abstract: *Close acquaintance with details of the CTBTO's International Monitoring System and the International Data Centre can tempt a keynote speaker to present the work as highly complicated, with success coming only via enormous effort. But stepping back from details such as the very size of data streams received by headquarters in Vienna, and of data sets accumulated after nearly 25 years of operations, it is more important to note the main achievement of the IMS and IDC — namely that the CTBTO draws appropriate attention to events which member States can choose to study in greater or lesser detail. Intense efforts can then be brought to bear on events of particular interest, as deemed necessary by any data user. This presentation will review the basic steps in detecting and analysing the variety of types of signals generated by nuclear test explosions. It will then present examples of how nuclear test explosions were recorded, first in the earliest days of nuclear weapons development; how these data changed over the 40 years leading up to the agreed CTBT text of 1996; and then how data acquired in the present century can be processed using the latest methods applied to broad areas.*

The goal of Invited Talk I01-722 was to discuss some of the newest work in seismology and convey the importance of some of the oldest data. It began with an overview of the large number of nuclear tests conducted from the 1940s until the 1990s, initially as atmospheric test explosions and then primarily as underground tests, after the signature of the Partial Nuclear-Test-Ban Treaty in 1963. Many nuclear tests were conducted in the era of analog seismic recording, including most of the atmospheric tests, and it is important to preserve these analog records.

There are two types of seismic waves that potentially detect nuclear tests: regional seismic waves seen at distances of less than 1500 km, and teleseismic waves, which emerge at large distances. The different steps of nuclear monitoring consist of detection, association, location, identification, attribution and yield estimation. This presentation focused mostly on location. The traditional method of location is based on triangulation, using for instance the time difference between the secondary (S) and the primary (P) arrivals. However, this method suffers from several flaws because it is based on a very small portion of the seismograms, uses small amplitude waves, and requires a local model to convert time differences to distance. Recordings of the announced nuclear tests by the Democratic People's Republic of Korea and nearby tectonic events (after 2017) were used as an example to illustrate a different method that takes advantage of the whole seismogram, including the portions with high amplitudes. The location map of events obtained from stations in neighbouring Manchuria and the Republic of Korea was presented to show how the method uses the differences in the seismograms themselves that are dominated by Lg waves at regional distances and can obtain very high precision on the location of the events. Although these methods have worked in limited areas for a long time, the research under discussion focused on applying them to wider areas, as explained in further detail in the presentation O3.5-398. The steps of monitoring then become quite different and consist, for a set of stations, of using templates for well-recorded events, cross-correlating them continuously against the archived waveforms, validating the detections, measuring the relative time differences for pairs of events that are near each other and recorded at the same station, and then using a double-difference method to relocate as many events as possible. This was applied to a large area in Central Asia, including all of Mongolia plus some of the neighbouring countries, between 2012 and 2016. It resulted in finding 33 times as many events in that area compared with the 1000 templates from the Late Event Bulletin (LEB) of the CTBTO that were used to find them. Many events, however, were detected using a template at one station only and did not allow for a refined location. Complemented by 40 additional stations of a temporary seismometer network deployed at the same time by Lehigh University, a relative location became possible, and the outcome is a series of clusters of events, most of which, based on the day of the week and the time of day when they occurred, are identifiable as mining blasts.

Overall, intense efforts can be brought to bear on events presented by the CTBTO that need further investigations by its States Signatories. The method presented would facilitate quick determination that many events can be positively identified by analysts reviewing these automatic results as mining events and therefore are of no concern for nuclear monitoring.

The location method presented can also be useful for earthquake studies to reveal lineations of small seismic events that may indicate the existence of dormant seismic activity with the potential of later reactivation of a large fault.

The yield of nuclear explosions is not the direct concern of the CTBTO, but it is still of interest for States Signatories to characterize the capabilities of the IMS network. Radionuclide measurements or seismic methods can be used to estimate the size of an explosion. There is one fundamental issue with seismic methods, which is to determine the fraction of the yield that is transformed into seismic energy. This point was illustrated by showing the work of Russian scientists who measured the seismic velocity in the zone at Semipalatinsk, Kazakhstan, where a 12.5 kt explosion had taken place. From comparing the original seismic velocities in the granitic rock with the post-explosion values, it was observed that a lot of the energy was absorbed in crushing the rocks in the immediate vicinity of the cavity and in the large ring where anelastic deformations occurred due to the explosion.

3.2. I02-718 – The CTBT Hydroacoustic Network at 25 Years

Speaker: Martin Lawrence[1]
Co-authors: Georgios Haralabus[2]; Mario Zampolli[2]; Peter Louring Nielsen[2]; Jerry Stanley[2]
[1]*Sydney Institute of Marine Science, Sydney, Australia*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: mwlawrence@gmx.com
Abstract: *This presentation addresses the history of the CTBT hydroacoustic network, from its broad definition during negotiations of the Treaty through its establishment over the 25 years following the opening for signature of the CTBT. Hydroacoustic network discussions during the negotiation of the CTBT will be addressed, including rationale for decisions that were made. The network concept was further solidified during the early years of the CTBTO, leading to the first Hydroacoustic Operational Manual. The early work on establishing the hydrophone stations required innovative thinking to establish stations that would work as specified, be highly reliable, and be as maintainable as possible. The progressive build-up of the hydroacoustic network has led to its current status of being the only fully certified technology in the CTBT network. It is a unique global observatory which is providing data not just for CTBT purposes, but also data for various civil and scientific uses. The underwater location of major elements of the hydrophone stations causes difficulties in sustaining them. Underwater repairs/replacement are very expensive, complex, and time consuming which provides a challenge in both installing highly reliable equipment and dealing with failure when it does occur.*

Invited Talk I02-718 constitutes reference material for the Treaty, the organization and the hydroacoustic network. It addressed the history of the CTBT hydroacoustic network from its inception during Treaty negotiations through the progressive 25 year build-up that led to its current status. The presenter chaired the original working group that proposed the types and number of hydroacoustic stations. Initial proposals of 20 and 11 cabled stations were rejected due to the elevated estimated cost. The inexpensive alternative of autonomous buoys was also rejected due to their inability to send real time data, in conjunction with concerns about long term sustainability. Supported by modelling studies, the final proposal was the current hydroacoustic network of 11 stations, comprising 5 T phase stations with near shore seismometers (100 Hz sampling frequency) and 6 hydrophone cabled stations with triplets of hydrophones horizontally separated by 2 km (250 Hz sampling frequency), as shown in Figure 1. These stations suffice for acoustic coverage of the world's oceans, also thanks to a natural phenomenon called the Sound Fixing and Ranging (SOFAR) channel, an undersea horizontal layer of water where sound travels at a minimum speed, reducing energy dissipation, thus travelling great distances. The depth of the SOFAR channel varies in different locations on the globe, as it mainly depends on temperature and hydrostatic pressure.

The presenter was the chair of the hydroacoustics working group when the CTBTO was established. By the time of his departure in 2006, 8 out of the 11 stations were installed. Currently, the entire hydroacoustic network is certified, making it the only fully certified IMS technology. The presentation emphasized the challenges associated with the installation and sustainment of the network after 2006 by including examples of challenging station re-establishments, such as station HA3 (Chile) on Robinson Crusoe Island in 2014 following the devastating 2010 tsunami, and the last and most challenging cabled station installation of HA4 (France) at the Crozet Islands in 2016. The ongoing efforts for the re-establishment of hydroacoustic station HA8 (UK) at Diego Garcia was also discussed. The station was originally installed in 2000, but in 2014 an underwater event, most likely a landslide, damaged the north cable.

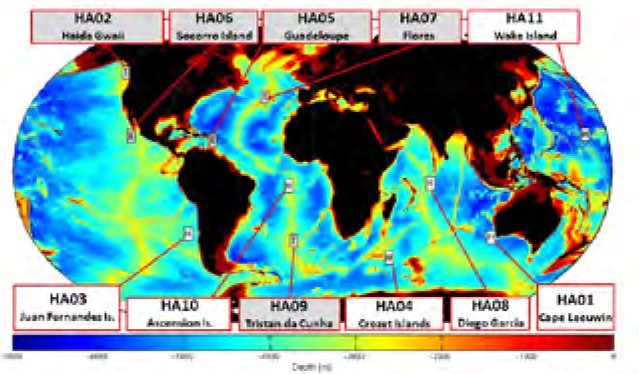


Figure 1: The hydroacoustic network of the IMS. Grey boxes indicate the five T phase stations, which comprise near shore seismometers that record waterborne hydroacoustic waves coupled upslope into the earth's crust. White boxes indicate the six hydrophone stations, which comprise moored hydrophones that monitor hydroacoustic waves in the water column.

The presentation also highlighted the value and uniqueness of the hydroacoustic network as a global passive acoustics observatory that monitors the world's oceans 24/7 for signs of nuclear explosions. This provides data not only for CTBT purposes, but also for civil and scientific applications, including the provision of real time data to tsunami warning centres. Hydroacoustic data is used for studies on marine mammal vocalizations, iceberg calving, underwater volcanoes, undersea soundscapes and ocean acoustic thermometry, as well as to support humanitarian assistance during crises at sea. Sound recordings from different sources, such as the vocalizations of marine mammals, were demonstrated. Two contributions of the IMS network in 2017 – the localization of the lost Argentinian submarine *ARA San Juan* and the first detection of hydroacoustic signals from the sixth announced underground nuclear test by the Democratic People's Republic of Korea – were discussed. The examples included in the presentation demonstrated that IMS hydroacoustic signals are of the highest quality and able to discriminate between different signal types over vast ocean areas and provide accurate direction of arrivals.

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1.
SnT2021 Conference Programme
Appendix 2.
SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

This 25th Anniversary Talk reminded the scientific community how to access this wealth of CTBTO data. In addition, it shared information on the technology foresight of the network by highlighting the modular design concept of a next-generation underwater node to facilitate modular on-site repairs. It concluded by underlining current issues, challenges and the overall value of this unique ocean monitoring network.

3.3. I03-714 – 25 Years of Infrasound Monitoring: Achievements and New Challenges

Speaker: Elisabeth Blanc[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: elisabeth.blanc@cea.fr
Abstract: *The infrasound International Monitoring System (IMS) is a unique tool for atmospheric observations due to its high capacity for long-range detection and localisation. Its development motivated technological innovation in sensors, array stations and automatic detection algorithms. The rapidly increasing number of certified stations provided a large diversity of man-made and natural events, well identified thanks to their precise description. Numerical simulations, based on revisited propagation laws, quantified its high performances and variability. Data analyses then clearly demonstrated that the simulation uncertainties originate from the middle atmosphere variability, which controls the infrasound waveguides and is under-represented in models. Unexpectedly, relevant atmospheric parameters were identified in signals from well-known sources such as volcanoes, opening new remote sensing possibilities. The IMS is associated with complementary networks in the Atmospheric dynamics Research InfraStructure in Europe (ARISE) framework, providing an improved description of the middle atmosphere disturbances relevant both for infrasound monitoring and applications such as medium-range weather predictions. Today, archived data reveals climate change effects on specific events such as icebreaking or lightning activity and a remote volcano monitoring system is developed to provide alert to civil aviation, showing the high IMS potential for weather, climate and civil security applications.*

Invited Talk I03-714 offered an historical review of infrasound technology from the early development of instruments to monitor the atmosphere for perturbations and through the years of renaissance of the infrasound technology, which was made possible with the negotiation process for the CTBT. The establishment of the CTBTO led to an era of rapid changes in infrasound technology, with the development of the IMS infrasound segment, the creation of the IDC system making use of seismic, hydroacoustic and infrasound (SHI) data, and the discovery and analysis of sources of infrasound signals.

Prior to the opening of the CTBT for signature, infrasound technology was relatively confidential, with a microbarograph global network established by the United States and France to monitor very large atmospheric nuclear tests, such as a 10 Mt test by the Soviet Union in September 1962, which was recovered at global ranges up to French Polynesia. After the era of atmospheric nuclear tests, technological progress continued at a slower pace and focused in particular on calibration campaigns. Historical data recorded during this period led to an early understanding of long range propagation of infrasound waves in the atmosphere, its complexity and dependence for source strength. This paved the way for the computation and first studies of detection capability, which helped to define the requirements assembled by the Ad Hoc Committee on a Nuclear Test Ban Working Group on Verification in 1995.

The renaissance of infrasound technology followed, with studies covering a wide spectrum of activities including the development, production and deployment of new, very sensitive microbarometric sensors, the design of wind noise reduction systems connected to the sensors and a joint effort to install acoustic antennas and process data using correlation based methods.

Progress was quick and notable in the early 2000s, with the certification of the first IMS infrasound station in Germany in 2001 and a growing number of certified stations, reaching 17 by 2004. This was logically accompanied by the discovery of new infrasound sources and an increased number of ground truth events. Meanwhile, new challenges also became apparent, such as the need to automatically classify signals or the issue of accurately locating infrasound events. Both tasks proved to be complex due to the inhomogeneity and constantly evolving propagation medium, the atmosphere, and the highly changeable and turbulent environmental conditions at the recording sites.

After 2005, the infrasound community continued to expand and investigated synergies with other technologies, such as seismology, in particular for the production of event bulletins and the study of ground motion generated by earthquakes producing infrasound waves. In order to continue advancing the technology, a number of calibration campaigns were organized, historical data sets were revisited, and unusual events were widely studied to test and evaluate propagation models, detection methods, atmospheric specifications and altogether the ability of the community to predict the detection capability of infrasound signals. The infrasound network was found to be more sensitive than predicted prior to the establishment of the IMS infrasound segment. In this context, an event that attracted worldwide attention was the scrutiny by infrasound researchers of the Chelyabinsk meteor (15 February 2013), which is still the most energetic event ever recorded by the IMS infrasound network. The event provided a global benchmark to evaluate all aspects of infrasound technology, from research algorithms to operational systems.

However, as new methods and sensors were becoming operational, these technical advances demonstrated the need to study further the dynamic processes of the middle atmosphere. Long term observations of continuous infrasound sources demonstrated knowledge gaps in the atmospheric models. This was illustrated with the case study of the eruption of the Etna volcano observed by infrasound station IS48 (Tunisia) over an eight year period. The eruptive chronology can be better reconstructed when gravity waves in the stratosphere are incorporated in the infrasound simulations. Particularly affected are the stratosphere and higher atmospheric layers, which have a large impact on infrasound wave propagation and thus affect the interpretation accuracy.

In recent years, research and development of infrasound technology continue to shift towards multi-phenomenology observations, synergies between technologies, accurately simulating wave propagation and pushing the boundaries of the knowledge of stratospheric dynamics, thanks to the near completion of installation of the IMS infrasound component and the growing IDC infrasound bulletin. New perspectives are emerging for infrasound technology, as it offers perspectives of quality diagnostics for numerical weather prediction models, which in turn would also benefit propagation modelling accuracy and reduce uncertainties. Scientific and civil applications, which were at a conceptual level a few years ago, are being tackled through international projects, such as the Atmospheric dynamics Research InfraStructure in Europe (ARISE) project funded by the European Union. A concrete illustration of progress on a civilian application is the demonstrated usefulness of infrasound technology in supporting the monitoring of volcanic eruptions that endanger aviation. The list of perspectives continues to grow, from climatological effects to understanding severe weather events like sudden stratospheric warming or thunderstorm activity. The infrasound community keeps finding new applications as it explores IMS data and IDC products, and as it now revisits the history of the recordings spanning up to 20 years for the first stations installed and certified.

The IMS infrasound segment is unique and has been offering a wide range of scientific and civilian opportunities, while challenges still need to be resolved in the next 25 years.

3.4. I04-717 – The IMS Radionuclide Network: A Unique Machine Not Yet Fully Exploited

Speaker: Anders Ringbom[1]
[1]*Swedish Defence Research Agency (FOI), Stockholm, Sweden*
Corresponding Author: anders.ringbom@foi.se

Abstract: *The IMS Network of 80 particulate and 40 radioxenon measurement systems is one of its kind in several ways. The global coverage combined with high time resolution contributes to a unique, steadily growing data set available to all CTBT member states. The requirements of the verification regime, formulated more than 25 years ago, prompted the development of new measurement technologies, such as automated particulate samplers and radioxenon systems. The area of radioxenon detection in particular got a considerable boost, and still remains a very active research area. However, I believe we just got started on the journey towards an even more effective verification regime. Besides describing the development of the past 25 years, I will try to look into the future and discuss a few topics that I believe will be important in the years to come. The development has so far mainly been focused on the individual measurement systems, achieving high measurement sensitivity with high reliability. Less effort has been put on optimizing the network as a whole, with the goal to maximize the combined capability to detect, locate and characterize release sources. I am convinced that by viewing the network as a single measurement system, many improvements still can be made, both with respect to measurements as well as data analysis. Another important remaining task is to identify as many background sources as possible. There are many unexplained detections in the network, and understanding the causes for these is absolutely crucial to the CTBT verification regime.*

Invited Talk I04-717 provided an overview of the 25 years of establishing the particulate and radioxenon monitoring network, as well as challenges and prospects for the future. The IMS network of 80 particulate and 40 radioxenon measurement systems is unique and in many ways extraordinary. It is the only radionuclide network with global coverage, and it has a higher time resolution than other networks. As of summer 2021, a total of 72 radionuclide particulate systems have been certified, including 27 automatic systems. The measurement of radioxenon isotopes in the field in automatic mode establishes the cutting edge of this special sensor technology, with 25 noble gas systems installed and certified (Figure 2).

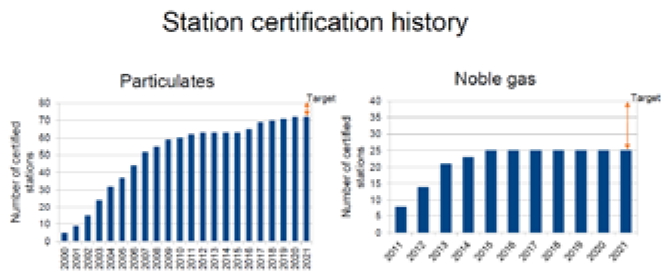


Figure 2. Number of certified radionuclide stations, 2000–2021.

With the build-up of the system, 25,000 particulate and 13,000 noble gas samples are now analysed annually. This unique and steadily growing data set is available to all CTBT States Signatories. Several histogram plots on the nuclide chart were presented to show the total historical occurrence frequency of CTBT-relevant radioisotopes. In addition, the fission products resulting from the Fukushima Daiichi nuclear power plant accident were shown separately, as well as the frequency distribution before 2011 and after 2012 (Figure 3). Although the number of noble gas samples is much smaller than the number of particulate samples, three out of the four radioxenon isotopes have so far been observed, more often than any other fission product. Cesium-137 is the most frequently observed CTBT-relevant isotope, followed by ^{135}Xe, ^{131}I and ^{134}Cs. The most frequently observed activation product is ^{24}Na. However, this isotope is normally of cosmogenic origin. The second most frequently observed activation product is ^{60}Co. Distribution of CTBT-relevant radionuclides from the Fukushima accident as

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP
SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

well as in the years since 2013 was also presented as histogram bars on the world map. This illustrates well that the releases from Fukushima affected mainly the whole northern hemisphere with a maximum at RN38 (Japan) and the IMS systems in North America. Since 2013, the highest number of occurrences was in Eurasia and northern Africa.

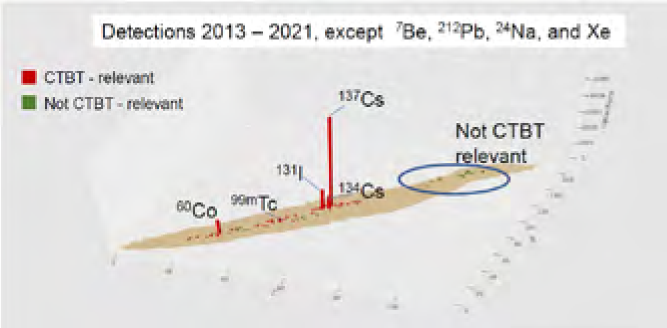


Figure 3. Detection of radionuclides, 2013–2021. CTBT-relevant isotopes are shown in red; those that are not relevant in green.

The presentation pointed out that an important remaining task is to identify as many background sources as possible. There are many unexplained detections in the network, and understanding the causes for these is absolutely crucial to the CTBT verification regime. Isotope ^{131}I was given as an example because it is quite frequently observed, and because it is the particle-borne isotope that is the most likely to be released from an underground nuclear test. For radioxenon, the global background and the types of facilities contributing to it were discussed in detail. The background is observed globally, but the difference between stations is high and on the timescale the observations are highly variable. Many sources are known, but not all. Even isotopic ratio analysis is not an obvious characteristic for source characterization because the background ratios can be close to ratios resulting from nuclear test releases. This source discrimination is even more difficult when the background sources mix with and disturb the ratios of a signal that may indicate a nuclear test. The average behaviour of the radioxenon background can currently be explained using known sources and atmospheric transport simulations. However, individual cases are more difficult to understand. Of special interest are the occasional observations of ^{135}Xe without any other radioxenon isotope present. Such observations are difficult to understand because the ratio of ^{135}Xe to ^{133}Xe from nuclear facilities is never above 10 and rapidly decays during atmospheric transport below unity. Since the sensitivity of IMS noble gas systems is always better for ^{133}Xe compared with ^{135}Xe, a pure ^{135}Xe observation without ^{133}Xe is not expected and still poorly understood. Solving this question is crucial for nuclear explosion monitoring because a high ratio of ^{135}Xe to ^{133}Xe is a strong indicator of a prompt venting from a nuclear test. The IMS noble gas component was successful in detecting two of the six announced nuclear tests by the Democratic People's Republic of Korea. Radionuclide station RN16 (Canada) detected ^{133}Xe that was clearly associated to a rapid venting from the test in 2006. Delayed releases from the test in 2013 were observed at RN38 (Japan) and RN58 (Russian Federation).

The requirements of CTBT monitoring, which were formulated more than 25 years ago, prompted the development of new measurement technologies, such as automated particulate samplers and radioxenon systems. The area of radioxenon detection received a considerable boost and remains a very active research and development area in sensor technology, analysis algorithms and data interpretation. The presentation maintained that the community of international CTBT experts has only just begun on the journey towards an even more effective verification regime and discussed a few topics that will be important in the years to come.

Thus far, development has mainly focused on individual measurement systems and achieving high measurement sensitivity with high reliability. Less effort has been invested in optimizing the network as a whole with the goal to maximize the combined capability to detect, locate and characterize release sources. Considering the network as a single measurement system opens the horizon for many improvements that can still be made, both with respect to measurements as well as data analysis. Due to the short half-lives of the relevant isotopes, the xenon detection coverage of the network needs to increase. This is a fairly new insight for two reasons: First, the released activity from an underground nuclear test was overestimated when the network was designed. Second, the network coverage was optimized with regard to ^{133}Xe, but ^{135}Xe, the shortest-lived isotope, has much reduced network coverage. This isotope is crucial for source discrimination and event timing. Furthermore, the methods used for location need to be improved, including uncertainty estimates in atmospheric transport modelling (ATM).

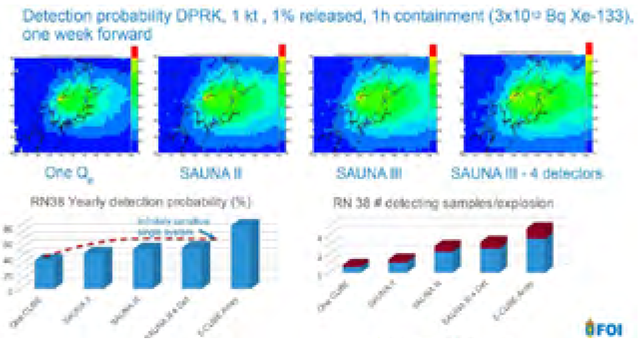


Figure 4. Estimated detection probability of a 1 kt explosion under various assumptions and monitoring systems.

A standard source assumption is used in Figure 4 to compare the effect on detection probability of a test by the Democratic People's Republic of Korea by the most impacted IMS location, which is RN38 in Takasaki, Japan. Enhancements of the sensor sensitivity have already approached the theoretical optimum because further enhancement of the detection probability depends on the atmospheric dispersion. As illustrated, detection probability can be improved by replacing the single sensors with an array comprising a set of five CUBE detectors, which is technically achievable.

3.5. Is6-454 – Machine Learning Prospects for Automatic SHI Processing

Speaker: Christos Saragiotis[1]
Co-authors: Ronan Le Bras[1]; Vera Miljanovic Tamarit[1]; Megan Slinkard[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: christos.saragiotis@ctbto.org
Abstract: *At the time of the opening of the Comprehensive Nuclear-Test-Ban Treaty for signature in 1996, machine learning was a relatively young but already established data analysis method in some fields. However, in seismology it had not reached a sufficient level of maturity to be considered for Treaty monitoring purposes. Furthermore, machine learning requires computational capabilities that exceeded the capabilities of most data centres at that time. Automatic processing at the International Data Centre (IDC) followed the standard, tested and established processing methods benefitting from knowledge that the seismological community had been accumulating for decades. As the years have progressed these barriers have been overcome; computational capabilities have reached unprecedented heights and numerous machine learning methods and tools have been developed in the field of seismology, including the NET-VISA software, a physics-based Bayesian approach, used operationally at the IDC. We will discuss further machine learning prospects for the IDC and in particular how deep learning can help the IDC enhance its capabilities regarding phase detection, identification, association as well as event location and classification.*

Invited Talk Is6-454 started with a brief history of machine learning. The idea of artificial intelligence was arguably born in 1950, when Alan Turing proposed what we today call the 'Turing test', according to which machines were deemed 'intelligent' or 'unintelligent'. Also, in 1952 IBM developed the first machine learning application. It was a checkers program that learned to play better the more it played. From that point on, machine learning saw some development with the introduction of

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP
SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Bayesian methods for probabilistic inference, but it was not as rapid as anticipated. This led to the so called AI winter. The AI winter was a period of reduced funding and interest in research on artificial intelligence. The term was coined by analogy to the idea of a nuclear winter, a severe and prolonged global climatic cooling effect that is expected to occur after a large scale nuclear war.

The 1980s and 1990s saw some developments again, especially thanks to the popularization of artificial neural networks (ANNs), in particular recurrent neural networks. Also, in the 1990s machine learning shifted from a knowledge driven approach to a data driven approach as scientists began creating programs for computers to analyse large amounts of data and draw conclusions, i.e. to 'learn' from the data. In the 2000s, support-vector clustering (and other kernel methods) and unsupervised machine learning methods became widespread, and in the 2010s deep learning became feasible. This led to machine learning becoming integral to many widely used software services and applications. To put this into the perspective of the CTBT, the Treaty was signed in 1996 and routine data analysis started in 2000, that is during the regeneration of interest and developments in machine learning and artificial intelligence.

Machine Learning in the Early IDC System

Machine learning has been present in the IDC processing pipeline from the beginning. Since the establishment of the early IDC system, machine learning has been used in three component (3-C) station processing for phase identification. Three neural networks, in particular multilayer perceptrons (MLPs), the task of each being to determine the relative likelihood that a detection belongs to each of a set of possible categories, are connected in cascade. The first neural network distinguishes between signal and noise; the second distinguishes between teleseismic and regional phases; and the third determines if the regional phases are P or S. Each of the MLPs comprises three layers (input, hidden and output) with 15, 6 and 2 neurons (or nodes), respectively. The input layer takes in 15 attributes, mostly related to polarization (rectilinearity, planarity, incidence angles and others) but also dominant period, horizontal to vertical power ratios and contextual (station specific) attributes. Naturally, all three neural networks were trained using historical data. The regional S phases identified by the cascaded MLPs further undergo a Bayesian inference stage to distinguish between Sn, Lg, Rg and Sx phases. This inference is based on the maximization of the probability for each phase given specific seismological features (time difference between the arrivals of P and S phase, dominant frequency, velocity, horizontal to vertical power ratio) and contextual features.

More Recent Machine Learning Algorithms in the IDC

One of the responsibilities of the IDC as stated in the CTBT is to "progressively enhance its technical capabilities as experience is gained" in its operation. To this end, the IDC has organized a number of scientific conferences and symposia where experts from around the world are given a platform to present ideas, inventions and algorithms that can potentially enhance the IDC processing pipeline. One such conference was the International Scientific Studies 2009 Symposium, which featured a session on data mining, with presentations of methods using machine learning for phase labelling and false association identification using support vector machines, a probabilistic (Bayesian) multiple-event location algorithm and notably the generalized-F (Gen-F) detector and NET-VISA.

Gen-F is a probabilistic detector that uses prior information about the signal (such as source power spectrum, source scaling, path effects and others) and noise (its power spectrum and spatial correlation) to detect seismic phases. It has been extensively tested in the IDC in the past few years and merged with the IDC code base. It will soon be available to NDCs and their experts for testing.

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

NET-VISA is also a Bayesian approach in phase association during the network processing stage of the IDC pipeline. It utilizes probability density functions derived from historical data (seismic events reviewed by analysts). At its inception, NET-VISA supported only the association of seismic events, but it has been progressively enriched with more and more capabilities (support for the hydroacoustic and infrasound technologies, interface for analyst review, improvements in the regional velocity model and error ellipses, among others). NET-VISA generates improved automatic event lists, thereby improving the quality of the automatic bulletins and reducing analyst workload. It has recently become part of the operational IDC software. Analysts can alternate between NET-VISA and the current phase associator, and NET-VISA is expected to become the default phase associator soon.

Future Prospects

In the last few years, there have been many developments in the field of machine learning methods in seismology. The IDC plans to exploit these advancements so as to enhance the processing pipeline as far as accuracy and computational efficiency are concerned.

One problem to tackle is back azimuth prediction for 3-C stations. Back azimuth estimation for array stations is performed using beamforming and is very accurate. However, the same cannot be said for 3-C stations, for which back azimuth estimation is performed using polarization analysis, which can be very unstable. This issue is particularly significant in regions where the IMS network consists of only 3-C stations or mostly 3-C stations (South America and Africa, respectively). BazNet (presented in P3.6-706) is a temporal convolutional neural network that makes single-station azimuth predictions accompanied by an uncertainty measure that correlates well with the back azimuth error. The latter will allow the exclusion of bad back azimuth predictions from the association algorithm and therefore enhance its speed and performance.

Another issue to mitigate is the refinement of automatically picked arrival times. It has been calculated that in 2020 more than 300,000 automatically picked arrivals (73 per cent of all automatically picked arrivals) were retimed by the IDC human experts, i.e. data analysts. Some of these retimings require f-k analysis and can be very time consuming. Assuming a modest 10 second retiming effort per arrival gives 875 person hours, which is about half a person year. A tool that reliably refines the automatically picked arrivals will therefore improve the quality of automatically created event lists and consequently reduce interactive review time. Such a tool the IDC plans to use is the deep neural network ArrNet (presented in P3.6-707).

Finally, another enhancement to incorporate into the IDC automatic pipeline to improve both automatic and interactive waveform processing is waveform denoising. In particular, the IDC is planning to test a station specific deep convolutional neural network developed by Sandia National Laboratories that decomposes waveforms into signal and noise by means of masking in the time–frequency domain.

There are many other machine learning algorithms that can potentially benefit the IDC processing pipeline. The IDC is always scanning the scientific literature for such opportunities. However, integration and testing of these methods is time and resource intensive, and the resources of the organization are finite. Therefore NDCs as well as independent scientists and researchers are encouraged to use CTBTO data to validate their methods in the Treaty verification context. A means of sharing data is vDEC, a platform that has been used for more than 10 years by scientists and researchers around the world for various purposes. The containerization of the IDC pipeline, a deliverable of the IDC reengineering project, will allow simultaneous testing and therefore reduce implementation, integration and testing time of qualifying algorithms.

Conclusion

The CTBTO has been using machine learning algorithms since the beginning. In the past, the application of such algorithms has been limited by computational limitations. These have largely been overcome due to improvements in computer hardware (processing power, memory capacity and storage). The IDC has already started testing promising machine learning algorithms that have the potential to significantly improve IDC processing capabilities as far signal detection, phase identification and association and waveform denoising. Other subprocesses or stages, such as event screening, can also benefit from the use of such algorithms and may be considered in the future.

3.6. Is1-353 – New Applications at the IDC for SHI Expert Technical Analysis

Speaker: Ivan Kitov[1]
Co-authors: Mikhail Rozhkov[2]; Yuri Starovoyt[2]; Ronan Le Bras[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Former CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: ivan.kitov@ctbto.org
Abstract: *The Preparatory Commission for the CTBTO routinely process time-series data from a global network of seismic, hydro-acoustic, and infrasound (SHI) stations. The data are processed to detect, build, locate, and screen events that may have characterization parameters similar to those from nuclear explosions. The observation and processing systems are required to be sensitive to small (e.g. low-magnitude) events, especially in unusual locations (e.g. aseismic regions). In order to match this requirement and to assist the State Parties to identify the source of specific events the IDC develops services combined in one SHI Expert Technical Analysis (ETA) Suite. The Parametrical Moment Tensor Estimator, ParMT (depth and magnitude determination through the moment tensor estimation) and the IDC historical master event-based Spot Check Tool, SCT, are the ongoing IDC developments. A promising avenue to improve the ParMT results, as well as for enhancement of IDC (mostly regional) locations, is to embrace the Ambient Noise Tomography technique in IDC practice. Receiver velocity models underneath IMS stations can be improved using the vast amount of gathered seismic background data. The same approach can be utilized for OSI data processing using the ANT-based velocity models produced with the noise data from SAMS array.*

Invited Talk Is1-353 discussed possible new applications at the IDC for SHI expert technical analysis. The Preparatory Commission for the CTBTO routinely processes time series data from a global network of seismic, hydroacoustic and infrasound stations. The data are processed to detect, build, locate and screen events that may have characterization parameters similar to those from nuclear explosions. The observation and processing systems are required to be sensitive to low magnitude events, especially in unusual locations (e.g. aseismic regions). In order to match this requirement and to help identify the source of specific events, the IDC develops services combined in one SHI Expert Technical Analysis (ETA) Suite. The Parametrical Moment Tensor Estimator (ParMT), which provides depth and magnitude determination through moment tensor estimation, and the Spot Check Tool (SCT), which is based on historical master events, are ongoing IDC developments. A promising avenue to improve the ParMT and SCT results, as well as enhance primarily regional IDC locations, is to embrace the ambient noise tomography technique in IDC practice.

For IDC Standard Event Screening the following criteria are used (among others): spectral ratios of phases, focal mechanism, relative excitation of seismic phases and comparative measures to other events and groups of events. This presentation was limited to seismic applications, where some experience and results are available to demonstrate potential improvements related to the objectives mentioned above. This would include finding small events, events in unusual locations, higher absolute and relative accuracy and lower uncertainty of location and depth estimation, estimation of standard and advanced event characteristics, estimation of focal mechanisms for the monitoring related events with magnitudes (m_b or Ms) above 4, spectral ratios of phases and comparative measures to other events and groups of events. In this presentation, several ETA-relevant applications were discussed. All of these applications aim to improve the completeness, accuracy and consistency of the IDC products: the bulletins and ETA reports. The objectives of ETA stem from these challenges and tasks.

The first application, SCT, is based on waveform cross-correlation (WCC). The basic idea behind SCT is to use information from historical Reviewed Event Bulletin (REB) events, i.e. from historical nuclear test data, and apply new detection, phase association and other algorithms and methods. SCT has two processing modes: automatic and interactive. Routine automatic processing includes proactive creation of the cross-correlation Standard Event List XSEL, which is similar to SEL3, and a comprehensive comparison of the events in SEL3 and the REB against the historical REB. This activity matches the task "comparative measures to other events and groups of events". The interactive mode is aimed at exclusive processing of a smaller subset of SEL3 and REB events with a crafted set of parameters. It is controlled by a Spot Check Interface, which is designed to match the requirements of many different roles. SCT is under development, and the updated frontend interface will be available soon for basic testing.

The main component of ParMT, the second application, is moment tensor estimation (MTE), which is a strategy to estimate the depth and magnitude of an event with an unknown source mechanism. MTE is similar to a hypothesis test, whereby an event depth, magnitude and moment tensor are proposed. For each parameter set, synthetic seismograms at regional and teleseismic distances are computed and then scored against the observed waveforms. In a uniform search space of depth, magnitude and focal mechanism, all candidate events are generated and their scores are estimated. Then, a post-processing step is performed, which selects the best fitting event and presents distributions of likely magnitudes, depths and source mechanisms. A powerful graphical user interface (GUI) has been developed, allowing for framework extension and introducing more functionality. Additionally, a synthetic seismogram generator has been introduced into the workflow. This synthetic data can be channelled into the MTE framework, and the sensitivity of the seismic network can be calibrated to known solutions. Figure 5 displays selected GUI applications.

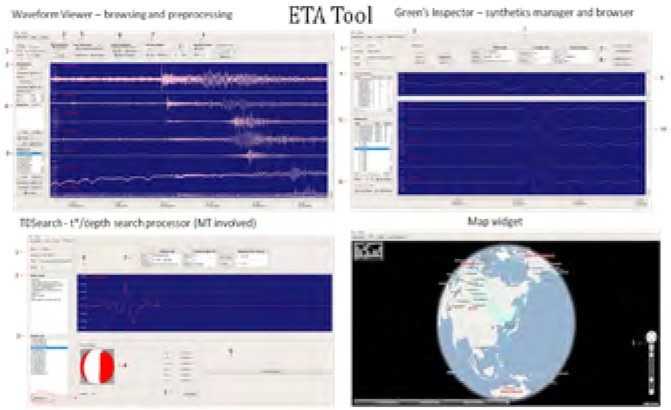


Figure 5. ParMT GUI applications.

The ParMT testing procedure involves estimation of the moment tensor and depth for events of various natures in order to study the focal mechanism screening criteria. The difficulties in interpretation of the source nature are illustrated in Figure 6, which shows a shallow earthquake in Canada characterized by a large isotropic component. The intersection of the earthquake and explosion populations seems to be an important issue when using the focal mechanism as a screening parameter. This effect is clearly observed in the mb/Ms screening criterion. For the ParMT application, however, the main goal is the depth estimate with the constraints from the focal mechanism. Depth is a powerful event screening parameter.

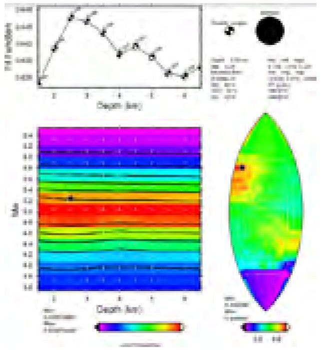


Figure 6. ParMT solution for an earthquake.

The third application is related to spectral ratios. The use of the ratio of regional P and S phases as a parameter discriminating natural seismic events and explosions is likely as old as the underground tests. However, its usage is effective only when there is an appropriate number of nuclear tests to build a reliable distribution of P/S ratios in a given region. The presentation discussed the comparison of the announced nuclear tests by the Democratic People's Republic of Korea and their aftershocks. The P/S curves for IMS stations PS37 (Russian Federation) and PS31 (Republic of Korea) demonstrate the deviation between the averaged explosion and aftershock P/S curves together with their standard deviations. The distance between the curves is more than four standard deviations. Since PS37 and PS31 are the two IMS stations detecting all aftershocks, their measurements are combined using the Mahalanobis distance.

The fourth application is connected to the third. Detection of ultra-weak aftershocks of the tests by the Democratic People's Republic of Korea is a challenge. WCC is used for the detection of signals with amplitudes close to the microseismic noise level. There are many well-detected aftershocks, which can be used as master events together with the tests themselves. Fifty-seven waveform templates from 6 explosions and 23 bigger aftershocks were used in routine cross-correlation processing within the multi-master framework. More than 100 reliable aftershocks were found since the first aftershock was detected on 11 September 2016 after DPRK5. Figure 7 displays the largest aftershocks belonging to the DPRK5 and DPRK6 sequences.

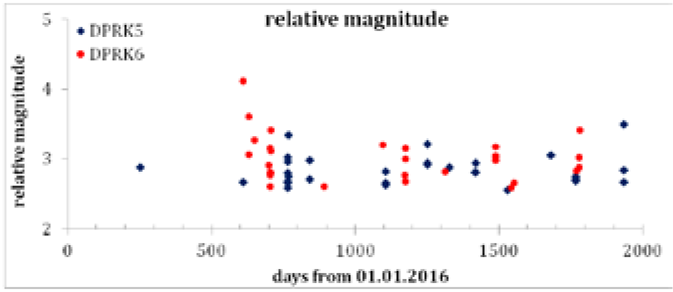


Figure 7. Relative magnitudes of the DPRK5 and DPRK6 aftershocks.

The application based on independent component analysis is used for separation of signals from different sources. Unlike principal component analysis, which treats the individual traces of an array separately, the independent component analysis approach takes into account the inherent links between all components of the multichannel signal. The separation of quarry blasts, regional earthquakes and the scaled Tohoku/DPRK3 and the Sumatra 2012/DPRK3 signal mixture demonstrates the power of independent component analysis. Another approach to the processing of multichannel seismic data is based on the multidimensional models: the hyper-complex and high-order tensor representation. This allows construction of multidimensional templates for cross-correlation based detection and location with the data recorded at multichannel IMS seismic installations. Hyper-complex numbers are the natural cases representing 3-C digital seismogram samples. Dealing with the composite observations (3-C arrays) may demand higher than four dimensional algebras. Tensor representation looks natural in this case.

For detection beams at array stations, one of many processing problems is the absence of empirical relative arrival times at the array sensors. Low velocity inclusions beneath an array may introduce significant disturbances in the relative arrival times and amplitudes. Ambient noise methods are passive methodology to retrieve velocity models of the uppermost layers. Spatial correlation of seismic noise and horizontal to vertical component spectral noise ratio could both be used for that purpose. In recent decades, the application of these methods produced accurate earth velocity models at spatial ranges from tens of metres to continental scales.

To conclude, the number of new algorithms and applications related to the recovery of structure, wave propagation, characterization of source functions and discrimination of events is rapidly growing in the realm of global and applied seismology. The IDC has to select and test algorithms and applications that are most appropriate for monitoring purposes. At the same time, the exclusive CTBTO mandate requires the development of very specific tools and applications driven by IMS data. The talk presented the experience with a few openly available applications as well as those developed at the IDC. Future usage of these applications depends on the results of extensive testing and the support of the monitoring community.

3.7. P3.5-507 – Is There Potential for Further Enhancing IDC Spectrum Analysis Methods of CTBT Radionuclide Measurements After 25 Years of Progressive Development?

Speaker: Boxue Liu[1]
Co-authors: Martin B. Kalinowski[1]; Abdelhakim Gheddou[1]; Lars-Erik De Geer[2]; Matthias Zähringer[3]; Mika Nikkinen[4]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Swedish Defence Research Agency (FOI), Sweden (Retired)*
[3]*Federal Office for Radiation Protection (BFS), Freiburg, Germany*
[4]*International Atomic Energy Agency (IAEA), Vienna, Austria*
Corresponding Author: boxue.liu@ctbto.org

Abstract: *This presentation is an overview on radionuclide analysis procedures at the IDC. There are three sets of approaches currently, the single channel analyser curve for particulate, the least squares regression on gamma- and X-rays peaks of xenon isotopes for high resolution spectra and the net count calculation method for beta-gamma coincidence spectra for noble gas, which are based on conventional frequentist statistics. Most daily IMS spectra have low counts close to background level. Decision thresholds by Currie's definition have been found to tend being underestimates, resulting in false positive detections. Enhancements on current methods could apply optimization regression analyses of standard spectra, 3-D fitting and gross counts, or machine learning which all are consistent with ISO standards on estimation of measurement uncertainty and characterization limits based on Bayesian statistics. Probability distributions of measurands, e.g. activity, concentration and isotopic ratio, could be obtained by the Monte-Carlo method, directly based on distributions of inputs of measurement spectra, calibration data and related parameters, resulting in realistic estimates for measurands, their uncertainties and associated limits of the coverage interval with a given probability. IDC radionuclide analysis reports could be enhanced by reporting not only results and their uncertainties but also associated characterization limits.*

Presentation P3.5-507 provided an overview of radionuclide analysis methods at the IDC. In the first half of the past 25 years, only particulate systems were in IDC operations. Basic analysis methods were implemented in the early years and addressed the challenge of low counts of CTBT-relevant radionuclides close to the natural background levels observed in most IMS samples. In the second half of the past 25 years, noble gas systems came into operation after more than a decade of developing the specific analysis methods. One technology uses high resolution gamma spectroscopy, the other technology applies beta–gamma coincidence measurements. For the latter, a few modifications of the standard operational method that is currently under implementation are being optimized for next-generation noble gas systems. Based on the achievements of the past 25 years, challenges and potential enhancements of IDC radionuclide analysis methods were described in view of further improving the quality of IDC radionuclide products.

There are currently three approaches being used: the single channel analyser curve for particulate, the least squares regression on gamma and X ray peaks of xenon isotopes for high resolution spectra, and the net count calculation method for beta–gamma coincidence spectra for noble gas. All of these approaches are based on conventional frequentist statistics. Enhancements of current methods might include optimization regression analyses of standard spectra, 3-D fitting and gross counts, or machine learning. Lessons learned have led to new requirements for noble gas analysis. Under-estimation of decision thresholds due to negative net numbers of counts needed to be corrected, as it led to a too high false alarm rate. Other improvements are including uncertainty components related to interference corrections, deconvolution of X ray contributions of xenon isotopes and radon, and estimating the covariances of net numbers of counts between regions of interest for isotopic ratio analysis. Along with the development of free memory detectors, the memory correction could be performed in a "smart" mode, i.e. only once a radioxenon isotope is detected in the associated gas background spectrum. Reporting results of the sample itself, the gas background and the sample with memory corrections separately would be a better solution for the systems with gas background measurements.

IDC data analysis is applied on a single measurement for each sample at IMS stations. No repeated measurements are available, with the exception of re-analysis of certain samples at CTBT laboratories. The spectrum analysis of a single sample is based on Bayesian statistics and the a priori distribution obtained in conventional frequentist statistics. The numbers of peak counts in the single measurement are estimated by using the likelihood function, which has the same formula as the probability density function (PDF) of the a priori distribution. The associated uncertainties are systematic uncertainties. The detector background is estimated based on the a priori distribution and related measurements. Most daily IMS spectra have low counts close to background level. Decision thresholds by Currie's definition have been found to tend to be underestimates for beta–gamma coincidence spectrum analysis due to assuming a PDF that is inappropriate for low-count samples, thus resulting in false positive detections. Developments and enhancements of analysis algorithms should be consistent with the estimation of measurement uncertainty and characterization limits based on Bayesian statistics.

IDC radionuclide analysis reports could be enhanced by reporting not only results and their uncertainties but also associated characterization limits as recommended in ISO 11929:2019. Traceability of analysis results for particulate samples is obtained by using standard sources with certificates from source providers. It is a pending issue for the traceability of the beta–gamma coincidence analysis. Standard sources are not available for all four xenon isotopes. On the other hand, the beta–gamma coincidence measurement, especially for a 4 pi detector geometry, is somehow an absolute measurement, where the activity values of standard sources are not needed for efficiency calculation.
Isotopic activity ratios of fission products detected at radionuclide stations of the IMS are used for characterization of a fission event. For both discrimination of a nuclear test and estimation of the explosion time, the isotopic ratio at the stop of collection is related to activity concentrations in the air plume instead of activities collected in the sample. Xenon flags for event screening are based on a Bayesian approach estimating the upper and lower limits of the isotopic ratio using Gaussian distribution. Lower limits of isotopic ratios are used as xenon flags in the IDC radionuclide products. Three pairs, $^{135}Xe/^{131}Xe > 5$, $^{133m}Xe/^{133}Xe > 0.3$ and $^{133m}Xe/^{131m}Xe > 2$, are deployed; and the other one, $^{133}Xe/^{131m}Xe > 1000$, still needs to be added.

The uncertainty of the isotopic ratio can also be estimated using Fieller's theorem, i.e. the upper and lower limits of the geometric coverage region formed by an ellipse. The nominal value of the isotopic ratio is estimated directly by the division of two concentrations and associated uncertainties given in IDC analysis reports. However, the isotopic ratios and associated uncertainties are dependent on not only concentrations but also their uncertainties and covariances. For a non-linear model of division operation, the biased value of an isotopic ratio and associated uncertainty need to be estimated by high-order Taylor terms, and they are dependent mainly on uncertainties of denominators, especially with large uncertainties of concentrations for low level samples. For low level samples, it is better to use the Monte Carlo method, estimating isotopic ratios and their uncertainties based on activities measured in the sample or associated peak counts directly.

3.8. Is2-283 – Advancements in Hydroacoustic Signal Processing at the IDC During the Past Two Decades and Plans for the Future

Speaker: Ronan Le Bras[1]
Co-authors: Peter Louring Nielsen[1]; Pierrick Mialle[1]; Noriyuki Kushida[1]; Paulina Bittner[1]; Martin B. Kalinowski[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: peter.nielsen@ctbto.org
Abstract: *Since its establishment in 1997, the CTBT IDC has been receiving data continuously from an increasing number of hydroacoustic stations. These stations are at present composed of 11 hydrophone triplets in the ocean and 5 T-stations (seismometers) on land monitoring for nuclear explosions in the oceans. This presentation summarizes advancements in the IDC automatic processing system from the early deployment of the system receiving data from a couple of hydroacoustic stations until today's hydroacoustic network. The advancement in IDC processing of hydrophone data has been obtained in underwater signal travel time modelling, improved rule-based signal classification, estimate of underwater signal detection and direction of arrival, introduction of early artificial intelligence for signal classification, and global network processing based on an advanced Bayesian framework (NET-VISA). These advances have improved the automatic signal classification, detection and event localization and therefore importantly reduced the amount of human interaction in the data processing. Further improvements of the processing are envisioned that includes detailed oceanographic models and databases, efficient complex signal propagation models, the Progressive Multi-Channel Correlation (PMCC) algorithm and the rapid development of machine learning algorithms. These future elements are proposed in an updated IDC automatic data processing paradigm.*

IDC processing of IMS hydroacoustic data, similar to the seismic technology, benefited from the monitoring experience acquired by specialized institutions during the Cold War. The difference was that seismic processing had open access to global networks, while virtually all experience with hydroacoustic data was found in the classified military domain, with applications such as submarine warfare. Therefore many processing concepts and algorithms had to be developed from first principles, with little to no cross-fertilization with the military domain.

Invited Talk Is2-283 provided an overview of the evolution of the IDC Automatic Processing System from the early period of the Treaty negotiations, with initial contributions from the Group of Scientific Experts Technical Tests (under the auspices of the Conference on Disarmament). The last of these tests took place at the Prototype International Data Centre, in Arlington, Virginia, USA, in 1995, and demonstrated the feasibility of centralizing the acquisition and processing of data from a global network of sensors in a manner that would allow sufficient speed. It was also understood that the level of automation and flexibility would allow further technical improvements in the future. The release of the R3 Automatic Processing System was developed to a level capable of nearly fulfilling the relevant Treaty obligations, including the processing of data from the three waveform technologies: seismic, hydroacoustic and infrasound. This version of the processing system was handed over to the IDC, which became responsible for its maintenance.

An ad hoc expert group met three times at the CTBTO premises in early 2000 to evaluate the processing of hydroacoustic data. The group proposed six high priority areas for further development: station specific processing parameters, multichannel processing of triad (synonym for the term 'triplet', which is used more commonly today) data, usage of T (in-ground source) and H (in-water source) phases in event definition and location, modelling of travel time and transmission loss, refinement of characterization of arrival time, and a spectrogram tool for interactive phase identification. These proposed enhancements led to the introduction of the Hydro Azimuth and Slowness Estimator (HASE) and most recently to Progressive Multi-Channel Cross-Correlation (PMCC), both of which are based on multi-channel correlation of hydrophone triplet data to estimate the direction of arrival and the apparent horizontal wave speed for both hydroacoustic (ocean) and seismic (ground) phases. The hydroacoustic processing estimated signal travel times and blockage maps were derived using advanced two dimensional ocean acoustic signal propagation models and oceanographic database information, which were the state of the art at that time. The rule-based automatic phase identification was continuously adjusted for better performance by increasing processing bandwidth, adding phase discriminators and optimizing processing parameters. Attempts were made to substitute the rule-based phase identification with neural network and support vector machines, but these methods have never been introduced operationally.

The presenter was a key player in the introduction of a new algorithm substituting the original Global Associator of events in the processing chain with a physics based, probabilistic Bayesian model and an inference algorithm embedded in Network Vertically Integrated Seismic Analysis (NET-VISA) software. NET-VISA considers all possible combinations of arrivals that maximize the likelihood for observed events. It was deployed to the operational network in 2018 to assist analysts and complement the Global Associator. The implementation of NET-VISA showed enhanced automatic event detection from the global IMS sensor network with improved contribution from the hydroacoustic stations compared with the original Global Associator. A relatively short term vision on the enhancement of hydroacoustic processing was provided that included utilization of complex oceanographic models and database information to capture, for instance, ocean eddies impacting ocean acoustic signal propagation. In the medium to long term, this oceanographic information is intended to provide input to high fidelity, three dimensional, global scale ocean acoustic signal propagation models that include horizontal refraction, reflection and diffraction to improve the accuracy of blockage maps, multiple direction of arrivals from the same ocean event, transmission loss (or attenuation) from event to hydrophone location and arrival time of each multipath. Similarly, advanced ray based models have the potential to provide more accurate travel time tables capable of also taking into account areas illuminated by horizontal refraction, reflection and diffraction.

A proposal for more efficient utilization of data recorded at IMS T stations to detect and characterize in-ocean events was also presented. The methodology is based on computing the transfer function from an in-ocean acoustic signal to an in-ground seismic signal at T stations using the spectral finite element model. The objective is to estimate the in-ocean acoustic signal at a virtual hydrophone by convolving the computed transfer function with recordings at T stations and extract features from the virtual hydrophone signal that may reveal information about in-ocean events.

Machine learning is also envisioned to become part of the automatic processing algorithm to identify and characterize in-ocean and in-ground hydroacoustic events with possible supplement of the above mentioned high fidelity modelling tools. It was also noted that machine learning has been demonstrated as effective to suppress noise in seismometer recordings. This technique could be applied to signals recorded at IMS T stations. The presented long term prospect of hydroacoustic processing aims at substituting the automatic processing chain all the way from detection to event screening with feedback between station processing and network processing. A candidate approach under development is a further expansion of the NET-VISA algorithm called SIG-VISA (where SIG stands for signal), which operates directly on the raw waveforms instead of relying on signal features as NET-VISA.

A comprehensive reference list with key publications relevant to the advancement of IDC hydroacoustic processing over the past 25 years was provided at the end of the presentation. Figure 8 shows schematically the present processing pipeline, as well as possible additions.

IDC Processing Chain

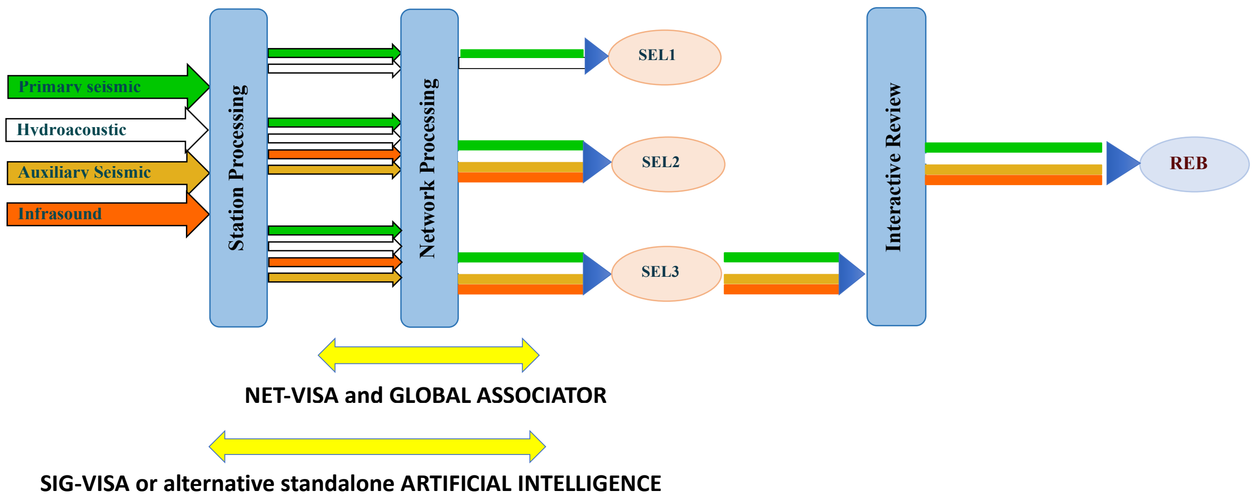


Figure 8. IDC processing chain for raw data covering all waveform technologies through station and network processing to automatically producing the Standard Event Lists (SELs) 1 to 3. Interactive review by analysts is performed on the SELs to produce the REB. The Global Associator of events in the network processing was delivered together with the early releases of the automatic processing algorithm. Recently, the probabilistic NET-VISA associator started to be used as a complement to the Global Associator, with a view to relying mainly on NET-VISA in the near future. A long term prospect is to replace both station and network processing by state of the art AI algorithms such as SIG-VISA, which has demonstrated at an early development stage to be in principle capable of producing the automatic SELs and automatic screening of events.

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP
SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

3.9. Is3-381 – Infrasound Processing System at the IDC, from Rudimentary to Maturity

Speaker: Pierrick Mialle[1]
Co-authors: Nicolas Brachet[2]; David Brown[3]; Paulina Bittner[1]; Ronan Le Bras[1]; Arora Nimar[4]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[3]*Former CTBTO Preparatory Commission, Vienna, Austria*
[4]*Bayesian Logic, Inc., CA, USA*
Corresponding Author: pierrick.mialle@ctbto.org
Abstract: *In 2001, when the first data from an IMS infrasound station started to arrive in near real-time at the IDC, its infrasound processing system was in a premature state. The IDC then embarked on a multi-year design and development of its dedicated processing system, which led to operational IDC automatic processing and interactive analysis systems in 2010. The IDC went on in the next ten years to produce over 40,000 infrasound events reviewed by expert analysts. In an effort to continue advancing its methods, improving its automatic system and providing software packages to CTBTO users, the IDC focused on several projects. First, the automatic system for the identification of valid signals was redesigned with the development of DTK-PMCC (Progressive Multi-Channel Correlation), which is made available to CTBTO users within NDC-in-a-Box. And second, an infrasound model was developed for automatic waveform network processing software NET-VISA with an emphasis on the optimization of the network detection threshold by identifying ways to refine signal characterization methodology and association criteria. Future improvements of the IDC processing system are planned to further reduce analyst workload that includes atmospheric propagation modeling and enhancements of the automatic pipeline components.*

Invited Talk Is3-381 revisited the achievements of the IDC in the analysis of infrasound signals over the last 25 years and provided an overview of current projects and future challenges. The last 25 years have been marked with rapid progress and developments in all aspects of infrasound technology, from instrument design, station installation, detection algorithm development to novel analysis methods of various events of interest (Figure 9).

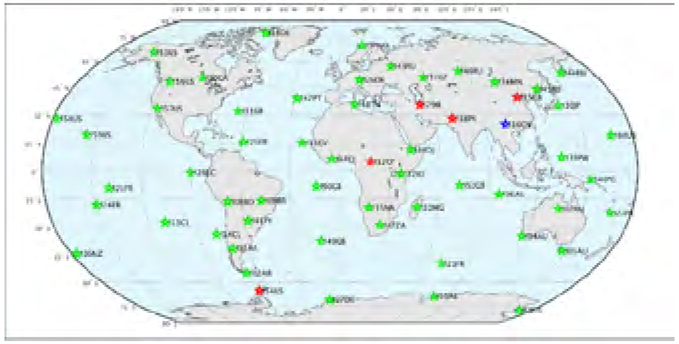


Figure 9: Global distribution of IMS infrasound monitoring stations (54 certified stations out of 60).

The infrasound system at the IDC took an intricate development path, starting as a rudimentary and ill-adapted processing system in the early 2000s and moving forward to become an improved automatic and interactive system after years of redesign, new development, testing and evaluation. Such progress allowed the IDC to introduce infrasound technology into its bulletin production in 2010. Over the last 11 years, the IDC produced a bulletin of reviewed events containing more than 40,000 infrasound events, including the infrasound signals from two announced nuclear tests by the Democratic People's Republic of Korea, which are of particular interest to the IDC (Figure 10).

To reach such capability, the IDC had to overcome a large number of challenges over the years. In its early days, the IDC had limited data to test the station detection system it had inherited, as the IMS infrasound segment was just starting to be built. It was only after several years and the certification of a sufficient amount of stations that the IDC was able to reach the conclusion that the initial processing system was inadequate.

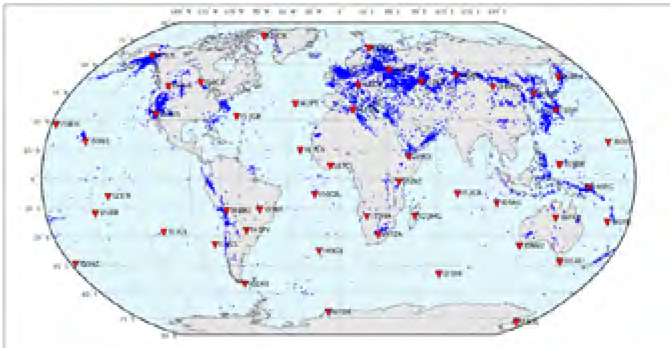


Figure 10: Late Event Bulletin since February 2010, when infrasound technology became fully operational at the IDC. Over 41,000 LEB events were identified through infrasound association.

From 2004 to 2010, infrasound technology returned to the development area of the IDC, and a programme was put in place to remedy this situation. All aspects of the IDC infrasound systems were carefully redesigned and developed, from station processing, signal categorization and network processing to cataloguing ground truth events, developing routine analysis tools and establishing analysis guidelines.

Infrasound data have been contributing to IDC bulletins since 2010. As needs arise, new projects are implemented to ensure that the IDC system remains state of the art, to support the installation and sustainment of the IMS infrasound segment and to prepare for the upcoming generation of tools for station processing with DTK-PMCC and for network processing with NET-VISA. The maturity of this technology also translated to the establishment of an infrasound training cycle for data analysts and the distribution of analysis tools via the NDC in a box software package, both of which contribute to expanding the infrasound community globally, especially to regions that previously lacked expertise.

The story does not end here, as a number of challenges remain on the path of the IDC to better understand and analyse infrasound signals and improve location accuracy. The unique operational experience of the IDC also serves as an example for possible future civilian systems to monitor explosive volcanic eruptions or near-earth objects impacting the atmosphere.

3.10. Is4-332 – Advancements in Atmospheric Transport Modelling at the CTBTO PTS During the Past Two Decades and Plans for the Future

Speaker: Jolanta Kusmierczyk-Michulec[1]
Co-authors: Andreas Becker[2]; Gerhard Wotawa[3]; Monika Krysta[4]; Pierre Bourgoin[1]; Anne Tipka[1]; Martin B. Kalinowski[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Deutscher Wetterdienst (DWD), Offenbach am Main, Germany*
[3]*Central Institute for Meteorology and Geodynamics (ZAMG), Vienna, Austria*
[4]*Bureau of Meteorology, Australia*
Corresponding Author:
jolanta.kusmierczyk-michulec@ctbto.org
Abstract: *CTBT monitoring for nuclear explosions is based on detection of waveform signals and the related event localization and on detection of traces of Treaty-relevant radioisotopes in the atmosphere. However, 25 years ago it was a challenge to obtain a clear link between a seismic event and a series of radionuclide detections. This was changed when the proper Atmospheric Transport Modelling (ATM) system with special post-processing routines was implemented and the relevant expertise built up. The effectiveness was demonstrated by providing ATM support during events of special interest like the Fukushima accident and the nuclear tests announced by the DPRK. The lessons learnt*

triggered enhancements. For example, the ATM support during the first DPRK event in 2006 led to the extension of backward trajectories from 6 to 14 days. More recent enhancements include an increase of spatial resolution from 1 degree to 0.5 degree and of time resolution from 3 hours to 1 hour. PTS aims at developing a world-class ATM system and takes all opportunities to validate it against systems from other major ATM centres like participation in multi-model exercises called ATM Challenge. This presentation also addresses the plans for the next years and vision for the longer term.

CTBT monitoring for nuclear explosions is based on the detection of waveform signals and the related event localization and on the detection of traces of Treaty-relevant radioisotopes in the atmosphere. However, Invited Talk Is4-332 explained that when the Treaty was established 25 years ago it was a challenge to obtain a clear link between a seismic event and a series of radionuclide detections. This changed with the implementation of a proper ATM system with special post-processing routines and the build-up of relevant expertise. A challenge related to source localization is that both remote and nearby sources might contribute to an elevated radionuclide level detected at an IMS station.

The quality of meteorological data is crucial in ATM. To assess and reduce the uncertainties of ATM results, the CTBTO works closely with the World Meteorological Organization (WMO) in the area of dispersion modelling. In the framework of the cooperation agreement that entered into force on 11 July 2003, the WMO supports the CTBTO by coordinating the ATM computations performed on request in the framework of the joint CTBTO–WMO Level 5 support system. Each detection identified by the IMS particulate network as Level 5 (multiple anomalous anthropogenic radionuclide measurements) results in the issuance of a request for support to Regional Specialized Meteorological Centres (RSMCs). In response, the RSMCs produce and upload their own backward simulations.

The ATM system deployed at the CTBTO was presented. It includes four major elements that are essential for the proper functioning of the entire system, i.e. acquisition of meteorological data, modelling, post-processing and visualization. The current ATM operational system is based on FLEXPART, a Lagrangian particle dispersion model, and driven by the global meteorological fields provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) and the United States National Centers for Environmental Prediction (NCEP) at a resolution of 0.5 degree. To enable the visualization of ATM outputs and the identification of possible source areas of radionuclide detections at IMS stations, the IDC has designed and developed the Web-connected graphics engine (WEB-GRAPE) software and its online version: WEB-GRAPE Internet Based Service (WEB-GRAPE-IBS).

Operationally, the ATM system is used in backward mode, i.e. from the receptor's location. If an IMS station detects an elevated level of radionuclides in a particular day, ATM calculations performed in backward mode are used to identify the origin of air masses. In many cases, detections occur at a single station, without nearby stations also measuring a signal. In this case, a simple field of regard (FOR) concept is used that can determine the location of release across a broad area. In this context, the FOR denotes the possible source region (PSR) for material detected within one single sample. FOR images are attached to every IDC analysis report on a radionuclide sample, or Reviewed Radionuclide Report. These static FOR images, as well as their animated version, help to denote the PSR for material detected within one single sample. On some occasions, multiple detections might occur at one or more IMS stations. Depending on the nature of these detections and on prevailing meteorological conditions, it is possible that all of these detections come from a unique source, and thus the PSR concept can be used to give a more precise possible source location. The PSR is produced for each grid point in space and time by calculating the correlation coefficients between the measured and simulated activity concentration values.

It was emphasized that a backward simulation is the method of choice if a source is unknown. In special cases, such as announced nuclear explosive testing by the Democratic People's Republic of Korea or the Fukushima Daiichi nuclear accident, when a source location is known, e.g. as a result of a seismic event localization, forward modelling is done. ATM in forward mode is used to predict which IMS radionuclide stations are likely to be affected by a potential radioactive release.

The major advancements in the ATM system during the past 20 years were also presented. The first ATM operational system deployed and used at the IDC was delivered by the Prototype IDC in 1999. Backward simulations were generated for all radionuclide systems using NCEP data. These results were archived for only six months and then deleted because of insufficient storage space. A mass storage system was procured in 2000, which facilitated the process of archiving data. Figure 11 gives an overview of the milestones associated with the enhancement of the global ATM system, including the main model FLEXPART and the visualization and post-processing software WEB-GRAPE. When the new updated version of FLEXPART became available, the ATM pipeline was also upgraded to include the new version. In 2014, in parallel with the WEB-GRAPE desktop version, the online WEB-GRAPE-IBS started to be developed.

The effectiveness of the ATM system was demonstrated by providing ATM support during events of special interest, such as the Fukushima Daiichi nuclear accident and the announced nuclear tests by the Democratic People's Republic of Korea. This support was broadly recognized. In February 2012, the Government of Japan made a voluntary contribution to the CTBTO for the enhancement of the ATM system. This contribution provided hardware infrastructure, which enabled the development of the higher resolution ATM system. In 2014, work towards increasing the resolution of the source–receptor sensitivity (SRS) fields from 3 hours temporal to 1 hour, and from 1.0 degree spatial to 0.5 degree, was initiated. The first

	Atmospheric Transport Modelling System						
Milestones	August 2002	2003	October 2004	November 2012	November 2013	December 2014	November 2017
Global ATM	FLEXPART 2.0	FLEXPART 2.0	FLEXPART 5.0	FLEXPART 5.0	FLEXPART 9.0	FLEXPART 9.0	FLEXPART 9.3 Optimized version for CTBTO
High resolution ATM				FLEXPART-WRF	FLEXPART-WRF	FLEXPART-WRF	FLEXPART-WRF
Software for visualization and post-processing		WEB-GRAPE Desktop	WEB-GRAPE Desktop	WEB-GRAPE Desktop	WEB-GRAPE Desktop	WEB-GRAPE Desktop WEB-GRAPE Internet Based Service (IBS)	WEB-GRAPE Desktop WEB-GRAPE Internet Based Service (IBS)

Figure 11. Milestones in the enhancement of the global ATM system, including the main model FLEXPART, the high resolution model FLEXPART-WRF, and the visualization and post-processing software WEB-GRAPE.

attempt to introduce these changes resulted in a significant increase in runtime, from about 4 hours to over 30 hours. To address these issues, a project on enhancements to FLEXPART software was initiated in December 2014, with a requirement that a simulation should take less than 12 hours in order to timely deliver the SRS products. In November 2017, scripts to create pre-processed meteorological files and a new version of FLEXPART (version 9.3) using these files were installed. In August 2018, the first milestone was achieved, and the spatial resolution of SRS files increased from 1.0 to 0.5 degrees. Two years later, work towards increasing the temporal resolution of the SRS fields from 3 hours to 1 hour was completed. Thanks to the optimization of FLEXPART and new ATM servers procured in 2019, the current time to complete a simulation does not exceed 4 hours. In total, 296 simulations are generated daily.

To meet the needs of the CTBT verification system, the IDC aims to develop a world class ATM system and take all opportunities to validate it against systems from other major ATM centres. The IDC participated in two ATM Challenges, or multi-model exercises, in 2015 and 2016. It is currently participating in the third ATM Challenge, which was launched in November

2019. The results of the first two exercises indicate that the performance of the CTBTO simulations is very good.

In conclusion, a brief overview was provided of future enhancements, which could include the upgrade of the ATM pipeline with the enhanced version of the Lagrangian particle dispersion model FLEXPART (version 10) or the study of the added value of a graphics processing unit (GPU) for further acceleration of ATM simulations. These changes would allow the upgraded pipeline to operate in a more optimal way and extend the ATM capabilities to include ensemble modelling for special expert technical analysis. Using ensemble prediction system (EPS) analyses would allow the estimation of confidence levels in ATM guidance.

3.11. Is7-604 – Review and Outlook of Radionuclide Screening Methods for Discriminating Nuclear Explosion Signals from Normal Radioactivity Background in the Atmosphere

Speaker: Theodore Bowyer[1]
Co-author: Martin B. Kalinowski[2]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: ted.bowyer@pnnl.gov
Abstract: *For the International Monitoring System (IMS) to be effective, it is vital that nuclear explosion signals can be distinguished from natural and man-made radioactivity in the atmosphere. The International Data Centre (IDC) applies standard event screening criteria, with the objective of characterizing, highlighting, and thereby screening out, events considered to be consistent with natural phenomena or non-nuclear, man-made phenomena. This presentation looks back to the initial understanding of possible screening methods in the early years of CTBT negotiations, summarizes the development of the categorization schemes and screening flags applied in the IDC reports for each particulate and noble gas sample, and reviews new proposals and open issues for discriminating nuclear explosion signals from normal radioactivity background in the atmosphere. There is still high need and ample room for enhancing radionuclide screening methodologies. This presentation sketches out what methods that were already demonstrated can be enhanced and implemented in the coming years, which novel methods appear promising to be developed and it creates a vision of highly effective screening for the longer future.*

Invited Talk Is7-604 provided a review and outlook of radionuclide screening methods that should support the discrimination of nuclear explosion signals from the normal radioactivity background in the atmosphere. For the IMS to be effective, it is vital that nuclear explosion signals can be distinguished from natural and anthropogenic radioactivity in the atmosphere.

The IDC should apply standard event screening criteria with the objective of characterizing, highlighting and thereby screening out events considered to be consistent with natural phenomena or non-nuclear, anthropogenic phenomena. When the system was implemented, radionuclide event screening was designed to group radionuclide detections and non-detections into categories called 'levels'. For particulate samples, five levels were distinguished, and for noble gas samples three levels were found to be sufficient. These levels are meant to provide quick information about the content of radionuclide measurements to NDCs so that they can easily decide for themselves which samples to further investigate. The term 'screening' is not applied in this approach. Instead, it is called a 'categorization scheme'. This consists of a set of CTBT-relevant radionuclides and a method for determining which concentrations are normal at a given station and which are anomalous. This categorization scheme has two fundamental issues. First, the list of CTBT-relevant radionuclides in particulate samples is very long, whereas most of these isotopes are not typical for a nuclear test if they appear alone. A concept of 'significant isotopes' has

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

been suggested as a subset of the CTBT-relevant radionuclides. The other and more severe issue is that nuclear explosion signals can appear at any concentration level, irrespective of their being categorized as normal or anomalous. As a result, prioritizing samples with anomalous concentrations for further investigation by an NDC bears the risk of overlooking a detection of a nuclear test.

In addition to the level scheme, the categorization schemes contain screening flags with the purpose of highlighting samples that are more likely than others to indicate a possible nuclear test. The IDC reports on noble gas samples include screening flags for isotopic activity ratios. The flag result is "Yes" if the isotopic ratio is larger than a certain threshold. These flags are also potentially misleading because the threshold is valid only for the case of an early observation of a rapid venting immediately following an underground nuclear test. Over time, the radioxenon isotope ratios resulting from a nuclear test will decrease due to radioactive decay, and the observation of a signal from a nuclear explosion will not result in a "Yes" flag. A possible enhancement to the particulate samples is to add flags for selected isotopic ratios. For noble gas samples, three ideas were mentioned in the presentation to enhance screening flags:

- Develop and implement the agreed flag "ATM backtracking to known sources";
- Add a flag for the isotopic activity ratio of $^{131m}Xe/^{133}Xe$;
- Optimize the threshold values for the isotopic ratios.

It should be noted that standard screening is applied in the IDC analysis report of every single sample. For high categorization levels, the Standard Screened Radionuclide Event Bulletin (SSREB) is created. Its purpose is to add further information relevant to screening. So far, it is merely a placeholder, repeating results of the analysis report and linking to any laboratory report if it exists. The SSREB still needs to be completed with the following information:

- Adding a list of all other samples that are likely related to the same radioactive release event;
- Constructing the possible source region (PSR) related to the event on the basis of ATM results.
- If available, including information derived from isotopic ratios and applying it to confine the field of regard (FOR).

There is still high need and ample room to enhance radionuclide screening methodologies. The biggest issue for discriminating nuclear explosion signals from the normal radioactivity background in the atmosphere is the high variability of the background in time and in location. The better the scientific understanding of the atmospheric radioactivity background, the better can screening methods work. The presentation called for more studies on the variability of backgrounds and specific cases of sources. The use of data collected at known facilities may prove useful to remove the effect of these sources. For example, Figure 12 illustrates the effect of using data from the National Institute for Radioelements (IRE) in Belgium to screen out detections at the noble gas system at radionuclide station RN33 (Germany).
New approaches are possible that make use of available information about the background variation and known sources. They still need significant development, but their feasibility has already been demonstrated. The residual concentrations with stack release data and ATM demonstrated in Figure 12 is an example.

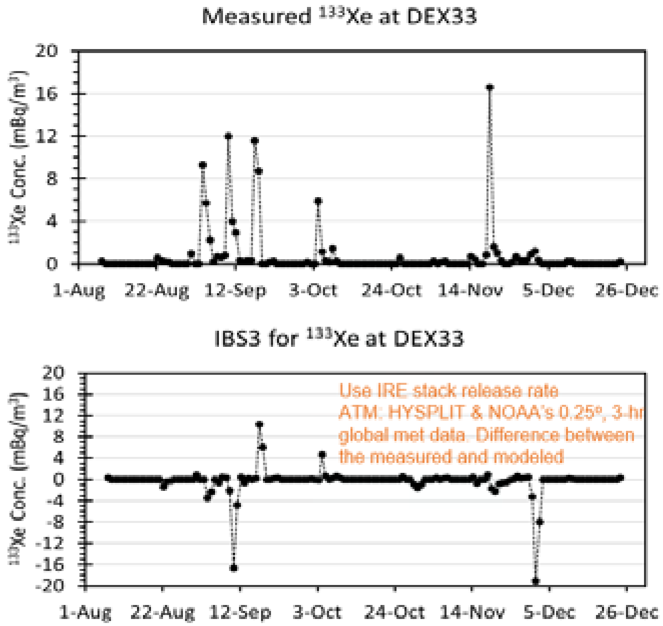


Figure 12. Demonstration of residual concentrations at the noble gas system at IMS radionuclide station RN33 constructed by subtracting from the measured concentration time series contributions of a well-characterized source (IRE) as predicted by ATM.

More generally, a global radionuclide model could be set up that assimilates all IMS observations and information on known sources to reconstruct the concentration of every relevant radionuclide at every point on earth (see Figure 13). With a recursive model and enough information about sources and backgrounds, this should be possible. The presentation proposed Identified Background Source Subtracted Screening (IBS3), a new screening product. Individual results from stations can be corrected based on a global model that accounts for known sources. When a non-zero result is expected at a station, the radioxenon concentrations are modified (subtracted). If the residual is high, this level is much more relevant for nuclear explosion monitoring than the levels of the current categorization scheme because it could indicate an unknown source. Accordingly, the presentation provided an example of how an enhanced radioxenon level scheme could be constructed using stack data.

Figure 13. The global radionuclide model

A different possible enhancement to current radionuclide screening has been explored by suggesting a combined categorization scheme that fuses the detections from noble gases and particulates into a common screening criterion. Unfortunately, the scenarios for release of radionuclides vary, as do the technologies, the timing of the equipment, etc. A common scheme has not been implemented, but there are some obvious cases in which this may make sense. Under some situations, a nuclear detonation will emit both radioactive noble gases and particulates. However, that is not the case for all events. Under some conditions only radioactive noble gases may be released, or only radioactive particulates, or both radioactive noble gases and radioactive particulates. More work on this is necessary.
In summary, the presentation concluded that much has been achieved in developing methods for radionuclide screening, but future developments will make the detection of radionuclide signals of nuclear explosions much more effective. The current approach to radionuclide screening could be significantly improved by enhancing isotopic ratio screening flags; adding

the possible source region based on multiple samples to the SSREB; developing and implementing the flag on ATM backtracking to known sources, including detailed information on the background of radionuclides from sources including stack release data; and possibly by fusing noble gas and particulate detections. The presentation created the vision that, ultimately, a global atmospheric model, analogous to the 3-D seismic model or infrasound propagation models, might be the best tool for highly effective screening. However, more work is necessary.

3.12. I05-727 – Status of Preparations for the Support of On-Site Inspections

Speaker: Peter Labak[1]
[1]*Earth Science Institute, Slovak Academy of Sciences, Bratislava, Slovakia*
Corresponding Author: labak.peter@gmail.com
Abstract: *Twenty-five years ago, in 1996, the opening of the CTBT for signatures was followed by the Resolution of the General Assembly on establishing the Preparatory Commission (PrepCom) for the CTBTO (Resolution). According to this Resolution the PrepCom is required to make all necessary preparations for the support of on-site inspections (OSI) from the entry into force of the Treaty. This contribution will provide an overview of the remarkable development and interrelationship of OSI capabilities particularly regarding the methodology for the planning and conduct of an inspection, the application of the permitted inspection techniques and the training of (surrogate) inspectors. It will also assess the status of preparations as specified in paragraph 15 of the Annex to the Resolution. Examples of co-operation between the States Signatories and the Provisional Technical Secretariat will illustrate some of the achievements. Ongoing technical developments and innovations will be discussed with a view to identifying opportunities for further improvement of OSI capabilities within the framework of the Treaty and its Protocol in order to make inspections more efficient and effective. Finally, thanks to the current status of the OSI capabilities, the potential for and ideas on using these capabilities for civil applications will be presented as well.*

Invited Talk I05-727 on the status of preparations for the support of OSI provided a comprehensive overview of OSI development over the past 25 years. The presenter has been involved in the development of OSI capabilities since 2001, particularly in the field of passive seismological monitoring for aftershocks, integration of information from various OSI techniques and data flow management for OSI. The presentation itself constitutes reference material for the Treaty, the CTBTO and the OSI community. It summarized basic characteristics of an OSI, gave an overview of the development of OSI capabilities based on the text in paragraph 15 of the Resolution establishing the Preparatory Commission for the CTBTO, and identified potential technical developments, innovations and opportunities to further improve OSI capabilities within the framework of the Treaty and its Protocol. In addition, the presentation shared ideas on the potential civil applications of OSI capabilities.

One identified key deliverable of the work in the past 25 years is the first comprehensive draft list of equipment specifications for use during OSI (CTBT/PTS/INF.1573). Its content is based on extensive development and testing of equipment for all OSI techniques with the exception of drilling. Development of OSI techniques required identification and understanding of relevant observables, elaboration of a possible concept of operations, and testing and validation of methods for recording and processing data. The crucial role of States Signatories and experts in the initial steps of development was highlighted. Later development that was led by the PTS and supported by the States Signatories was based on the OSI strategic plan CTBT/PTS/INF.677 and its revision CTBT/PTS/INF.793. It was decided that such development of OSI capabilities prior to entry into force of the Treaty would be conducted in cycles, and the results of the development would be validated in large scale integrated exercises. Examples of this approach include a Field Experiment in Kazakhstan in 2002 and Integrated Field Exercises in Kazakhstan in 2008 and in Jordan in 2014. Examples of the development of selected OSI techniques based on the results of two OSI action plans executed by the PTS in the periods 2009–2013 and 2016–2019 were also presented.

Another key result of the work in the past 25 years is the OSI training programme. Three phases of development of the OSI training programme were identified for the period until 2014. The first phase, until 2006, included the execution of an experimental training and exercise programme. The second phase of development was based on a long range training plan and covers mainly the period prior to the first Integrated Field Exercise in 2008. The third phase included testing and adjustment of the training programme in closed cycles as preparation for the Integrated Field Exercise in Jordan in 2014. Thus far, three training cycles have been performed. The curriculum focused on new inspectors, which were nominated by States Signatories, and included introductory and advanced blocks followed by a field exercise. During the programme testing, many useful lessons emerged (e.g. refresher training, use of remote training). The COVID-19 pandemic highlighted the need to use new training methods and reconsider certain aspects of the training programme.

The Quality Management System (QMS) for OSI was put in place in 2011. It includes QMS Manuals, Standard Operating Procedures and Work Instructions, as well as a number of forms and templates for use in the field. As a result of this effort, a set of 83 documents for operational procedures together with other OSI related field documents were used during the Integrated Field Exercise in Jordan in 2014.

The presentation also identified necessary infrastructure as a key enabler to conduct OSIs. Specifically, infrastructure is required to support the launch and conduct of an OSI within the strict OSI timelines and to ensure proper calibration, maintenance and protection of OSI equipment. Such infrastructure was put in place at the CTBTO Operations Support Centre (COPC) at PTS headquarters in Vienna and at the TeST Centre that includes the Equipment Storage and Maintenance Facility for OSI equipment in Seibersdorf, Austria. Another important aspect is field infrastructure, i.e. for sustainable operation of the base of operations, which has advanced in recent years.

The potential for technical developments and innovations was identified as well. The following priority areas were identified:

- Development of remaining techniques (e.g. resonance seismometry, active seismic surveys and drilling) and finalizing the development cycle of existing techniques;
- Development of equipment that increases efficiency and efficacy of conducting OSIs;
- Development of capabilities for OSIs in other than standard environmental conditions;
- Development of capabilities for OSIs in environments other than underground.

3.13. Is5-239 – Development of the First Comprehensive Draft List of Equipment for Use During OSIs

Speaker: Gregor Malich[1]
Co-authors: Xavier Blanchard[1]; Peter Labak[2]; Robin Riedmann[1]; Guillermo Rocco[3]; Aled Rowlands[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Earth Science Institute, Slovak Academy of Sciences, Bratislava, Slovakia*
[3]*GeoRun Limited, Vienna, Austria*
Corresponding Author: gregor.malich@ctbto.org
Abstract: *The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (Commission) is required to develop and prepare a list of equipment for use during on-site inspections (OSIs). The Commission started work on this verification task as early as during the first OSI workshop in 1997 and has since considered both the structure of the list and the specifications of the equipment to be listed. A proposal for the first comprehensive draft list of equipment for use during OSIs has been presented by the Provisional Technical Secretariat of the Commission as a result of the implementation of OSI Action Plan 2016-2019. Taking into account relevant Treaty provisions and guidance from the Commission's policy making organs, it covers all permitted inspection activities and techniques with the exception of drilling and is currently undergoing review by States Signatories. This presentation provides a summary of the development of the first comprehensive draft list of equipment for use during OSIs from the outset. It highlights how advances of science and technology have influenced proposed specifications of OSI equipment since the CTBT opened for signature and outlines why the draft list will mark an important milestone in the development of OSI capabilities.*

Invited Talk Is5-239 on the development of the first comprehensive draft list of equipment for use during OSI provided an historical overview and deep insight into the process of drafting the list. The presenter was involved in the development of the equipment list in recent years and led the process of consolidation and harmonization of the list entries for various OSI techniques. The presentation itself constitutes reference material for the Treaty, the CTBTO and the OSI community.

The presenter noted that the development of an OSI equipment list is required by the Resolution establishing the Preparatory Commission of the CTBTO (CTBT/MSS/RES/1). The Commission started work on this verification task as early as the first OSI Workshop in 1997 and has regularly considered both the structure of the list and the specifications of the equipment itself.

States Signatories provided initial ideas on equipment specifications. The Integrated Field Exercise in Kazakhstan in 2008 and OSI Workshop-18 in 2010 (CTBT/WS/OSI-18/1) also provided valuable input for subsequent work. In early 2011, the OSI Task Leader summarized the status of discussions in Task Leader Paper CTBT/WGB/TL-4/40 and presented a proposal for the format and structure of the equipment list. Experts from States Signatories worked on this basis during OSI Workshop-19 that year (CTBT/WS/OSI-19) and drafted the equipment specifications for initial period techniques. As a follow-up, the PTS issued Information Papers with equipment specifications for selected OSI techniques. During OSI Workshop-23 in 2016, the equipment list was further developed on the basis of expert input from States Signatories.

Methodological enhancement of the work on equipment specifications is linked with the execution of the OSI Action Plan 2016–2019 by the PTS. A series of Information Papers on equipment specifications for OSI techniques was made available in 2019–2020.

Through the consolidation of the findings of the OSI Action Plan 2016–2019, the PTS finalized the first comprehensive draft list of OSI equipment specifications, which was submitted to Working Group B in 2021 as Information Paper CTBT/PTS/INF.1573 (Figure 14). The draft list was prepared in accordance with guidance provided by the OSI Task Leaders and Working Group B on the structure of the draft list of equipment. The document proposes specifications relating to core equipment for inspection activities and techniques specified in paragraph 69, Part II, of the Protocol to the Treaty, with the exception of drilling (paragraph 69 (h)). It is now offered for in-depth technical discussion with national experts with the objective to consolidate the draft list prior to its consideration by States Signatories at subsequent sessions of the Commission.

4 Highlight Talks

4. Highlight Talks

4.1. Highlight Talk on the Solid Earth and Its Structure

H1-720 – Imaging the Earth's Deep Interior Using Seismic Waves

Speaker: Barbara Romanowicz[1,2]
[1]*University of California, Berkeley, CA, USA*
[2] *Collège de France, Paris, France*
Corresponding Author: barbara@seismo.berkeley.edu

Abstract: *Forty years ago, the first global seismic tomographic models revealed the presence of two large, antipodal, structures at the base of the Earth's mantle, now known as "large low shear velocity provinces" (LLSVPs), that had no obvious relation to surface geology or mantle dynamics as understood from plate tectonics theory, and as reflected in near surface seismic structure. With the expansion of digital, very broadband seismic networks and related on-line databases, combined with improvements in theory and computer power, the resolution of mantle elastic structure has progressively improved. In this lecture, I will illustrate how state-of-the-art imaging techniques allow us to: track the fate of tectonic plates that dive back into the mantle beneath the Pacific "ring of fire", improve our understanding of the morphology and role of the LLSVPs, and follow the paths of deeply rooted hot mantle plumes, as they ascend towards the surface and are expressed there in the form of hotspot volcanism (of which Hawaii and Iceland are prominent examples). I will present some of the open science questions, technical challenges for further progress in full waveform tomography, as well as possible paths ahead to address them, combining tools from seismology and other geophysical disciplines.*

In Highlight Talk H1-720, Barbara Romanowicz discussed advances in our understanding of the structure and dynamics of the interior earth as a result of studying seismic information. She described how normal modes and seismic velocities reveal the internal structure of the earth and emphasized the strength of seismic tomography.

Global seismic science started in 1889, when a signal from an earthquake in Japan was recorded and identified in Germany. The 100 years following this first measurement led to the discovery and understanding of the one dimensional structure of the earth, including the various regions of the core and the mantle (PREM model, 1981 - 1D reference model, depending only on radius).

In the last 30 years, tools have been developed to improve understanding of the three dimensional structure and dynamics of the interior of the earth. Tomographic methodology has greatly advanced. However, one of the challenges is that both the sources and sensors for seismic tomography, including the earthquakes used as the sources of illumination and seismic stations, are not distributed uniformly. Seismic stations are especially scarce in oceans.

Already in the 1980s, maps of shear wave velocities from tomography were obtained. At 100 km depth they were shown to reflect plate tectonics. Azimuthal isotropy changes with depth and reflects alignment of olivine crystals (the main constituent of the upper mantle) with the flow. At 50 km depth, fossil plate directions from 150 to 180 million years ago are recorded, while deeper in the asthenosphere, at 150 km, current plate motions are reflected.

At the top and the bottom of the mantle (100 km and 2900 km, respectively), there are strong peaks in the spectrum of heterogeneity at long wavelengths (<10 degrees). This is a motion that shows that the entire mantle behaves as a convective system. Slabs pond at the transition layer at 660 km depth (where there is a known phase change), but also at 1000 km depth (where there is no consensus about the physical cause).

At 2800 km, i.e. 100 km above the core–mantle boundary, rings of fast velocities going through the poles are observed. Between them, there are two regions of low shear velocities, or large low shear velocity provinces (LLSVPs). These might manifest earth rotation in the past (these LLSVPs might have been stable for 250 million years), when viscosity was lower in the lower mantle. The LLSVPs have sharp edges, possibly a result of distinct composition, and may be denser than the surrounding mantle.

An interesting phenomenon is the occurrence of hotspots and mantle plumes in places like Hawaii, far from plate boundaries. In Hawaii, the age of extinct volcanoes increases to the west in the direction of plate motion, from zero age (active volcanoes) gradually to 76 million years. Hot plumes might come from the core–mantle boundary. Isotopic composition in these hotspots is different from other regions (examples are the proportions of Nd and Sr isotopes and the ratio of ^{3}He to ^{4}He). Ocean island basalts show a mixture of primitive mantle and recycled oceanic/continental crust/lithosphere.

Low velocity regions might be missed if one looks only at arrival times as opposed to the full spectrum. An important development is full wave tomography that analyses full seismograms. In the last 10 to 15 years, tools have been developed to compute synthetic seismograms in complex three dimensional earth models by numerical integration of the equations of motion, for which the spectral element method (SEM) is the preferred method. Synthetic seismograms are then compared with the observed 'full' seismograms. Computation resources are still needed, but now it is possible to have improved resolution, in particular for short wavelength low velocity features. With these improved methods, it was possible to obtain clearer pictures of plumes going from the core–mantle boundary to the Macdonald and Pitcairn islands in the Pacific Ocean, and also in regions near Cabo Verde, the Canary Islands and Iceland in the Atlantic Ocean. The basis of these plumes is surprisingly thick, probably more than 400–500 km. Features that appear later in time in seismograms ('postcursors') indicate the existence of smaller ultra low velocity zones (ULVZs) with large velocity reduction of approximately 20 per cent (compared with 3 per cent for LLSVPs), for example at the base of the Hawaiian plume.

A list of interesting standing research questions was shared with participants. Among them: How tall are the LLSVPs, and are they bundles of plumes? Do all major plumes contain ULVZs at their roots? Is there a layer of primordial material at the core–mantle boundary? Can the distinct signature of hotspot volcanism come from the core? Do plates drive secondary scale convection in the upper mantle, or is it the other way around?

What happens at 1000 km depth, the boundary of mantle dynamics where the change of deformation properties is unknown, is still an open question, unlike the transition layer at 660 km depth.

In terms of future developments, the presentation emphasized that more ocean observations are needed. These can be obtained using broadband arrays installed temporarily and sensors on floats (e.g. MERMAID floats). Larger apertures are desired. The concept of a tomographic telescope focusing on regions of interest, utilizing a collection of sources around it and numerical time reversal mirrors, was also highlighted.

4.2. Highlight Talk on the Oceans and Their Properties

H2-716 – Improving Ocean Monitoring Through the Expansion of the Global Seismographic Network on the Sea Floor

Speaker: John Orcutt[1]
[1]*University of California, San Diego, CA, USA*
Corresponding Author: jorcutt@ucsd.edu

Abstract: *There is rapidly expanding interest in the application of seismological tools for exploring the structure and dynamics*

of the seafloor from the inner core to the nature of the ubiquitous sediments which cover most of the seafloor. New technologies are making access to the oceans less expensive, while recently acoustic telemetry has supported the continuous transfer of data from broadband systems at the seafloor to autonomous vehicles and thence to satellites and laboratories with latencies of 2-3 minutes. The growing availability of Low Earth Orbit (LEO) communications satellites will reduce latency while increasing bandwidth. New seafloor sensors have reduced noise levels comparable to those of the best stations on land. New batteries and compact electronics have extended seafloor lifetimes to 1-3 years. There are few barriers to growth of capabilities at rates that are comparable to consumer electronics with technological turnovers of no more than three years. Of course, this requires a continuous evolution of the seafloor technologies at a similar pace. Novel ocean technologies have the potential of enhancing the monitoring of the ocean environment and complement the CTBTO's hydrophone network of moored hydrophones. Surveillance systems that serve ocean data will become ubiquitous and less expensive than present systems. Overall, improved data rates and enhanced knowledge of the complex structure of the seafloor can contribute to a wide range of scientific initiatives linked to the United Nations sustainable development goals and hazard mitigation.

In Highlight Talk H2-716, John Orcutt underlined the importance of global ocean acoustic instruments in detecting nuclear tests and presented state of the art technologies associated with the expansion and sustainability of the Global Seismological Network (GSN) on the sea floor. His presentation incorporated information and technology foresight from the coordinated efforts of scientific committee(s) and research groups aiming to establish a long term, automated, broadband seismic monitoring network on the global sea floor.

The prototype stations are envisioned to consist of groups of at least five closely spaced ocean bottom seismometers covering seismic wave frequencies of 0.001 Hz to 25 Hz. An assembly of multiple seismometers facilitates redundancy and noise reduction. Moreover, buried seismometers are considered for further noise reduction, provided that the sediment type at the deployment location allows for burial. For this purpose, a very interesting autonomous self-buried system was invented. In addition to the seismometer, the platform incorporates pumps and batteries that enable it to be self-buried approximately 1 m into soft sediments. At the end of the mission, the pumping is reversed, and with the help of an incorporated flotation device the entire assembly can rise to the surface for data download and reuse. A sketch of the self-buried seismometer assembly and the stages of the burial and recovery process is shown in Figure 15.

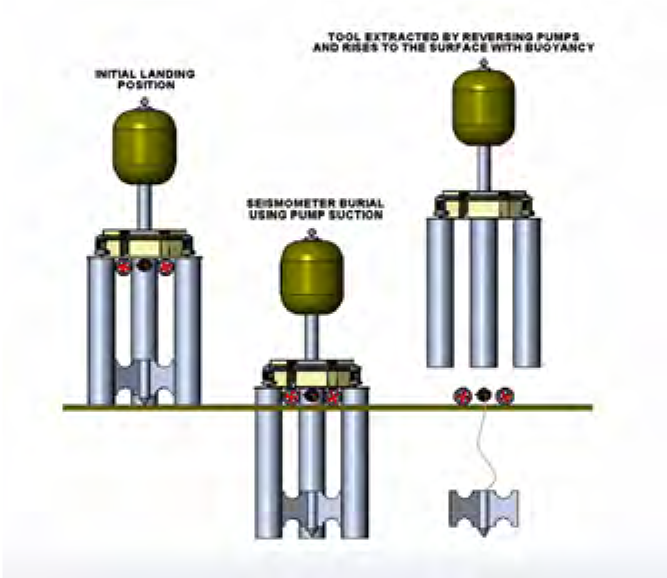


Figure 15. Self-buried seismometer assembly and the stages of the burial and recovery process.

The deployment can take place from a ship. In fact, there are already prototype autonomous ships with the capability to deploy and recover instruments from the sea floor. Autonomous deployment and recovery will reduce maintenance, installation time and costs.

The presentation included various options for data communication from sea floor seismometers, for cases where depth/distance from the sea surface or an appropriate submerged relay render such communication possible. In general, moving full bandwidths of data to shore is problematic. Wave gliders can be used to download data to the laboratory, but the water depth, data rate and weather conditions impose limitations. Acoustic and optical means of communications are needed to transfer large amounts of data. The examples included in the presentation showed a transfer rate of 10–20 Mbits/sec over 150 m of transmission range for the optical modem, and 5 kbits/sec and kilometres of range for the acoustic modem. The example of an autonomous underwater vehicle platform with an optical high speed telemetry model that can operate up to a transmission range of 600 m was shown. An alternative platform would be an oceanographic vessel that lowers a communication system from a winch to the sea floor to transfer large amounts of data to the ship and subsequently to shore. Technology foresight includes modems that could be lowered from an autonomous platform, but further development in this direction is needed.

Regarding power for autonomous systems, an innovative method of generating power at sea was presented, which is particularly interesting in conjunction with an overall context where batteries are becoming less expensive and more efficient. The method exploits the significant temperature change from the depth of the sea floor to the ocean surface. It is based on a phase change of a special material from solid to liquid during the depth/temperature change cycle from the sea floor to the sea surface that is repeated many times during the day to generate power. Moreover, since the power system needs to perform the depth/temperature change cycles from the sea floor to the surface, it can also be equipped with satellite communication modules for data transfer while at the sea surface. The growing availability of low earth orbit (LEO) communications satellites will reduce latency and increase bandwidth. Various examples were presented, including the Starlink LEO satellite network with a constellation of 1635 satellites in orbit and plans to significantly increase this number in the future.

The presentation also elaborated on various civil and scientific applications that would benefit from an increased ocean floor monitoring capability through the expansion of the GSN. Tsunami warning was underlined through examples of early tsunami detection using not only sea floor seismometers but also IMS hydrophones and/or the entire IMS waveform sensor network. Ocean thermometry examples were associated with global warming studies. Continuous scientific interest was also demonstrated for seismic tomography of the earth (inner and outer core, lower mantle, asthenosphere, lithosphere structure, core dynamics, etc.), subduction zones, anisotropies, attenuation, discontinuities and internal boundary studies, teleseismic earthquakes, and explosion detection, the latter being of high interest to the CTBTO. Indeed, novel ocean technologies have the potential to enhance monitoring of the ocean environment and complement the IMS network of moored hydrophones. Finally, the National Science Foundation Convergence Accelerator programme was offered as an example of a multidisciplinary platform to merge ideas, technologies, approaches and innovation processes to advance ocean monitoring through the expansion of the GSN on the sea floor.

4.3. Highlight Talk on the Atmosphere and Its Dynamics

H3-715 – Predictability of the Evolution of the Earth System and of the Atmosphere: A Historical Perspective and Future Challenges – Weather, Climate and Air Quality

Speaker: Guy Brasseur[1]
[1]*Max Planck Institute for Meteorology, Hamburg, Germany*
Corresponding Author: guy.brasseur@mpimet.mpg.de

Abstract: *Our understanding of atmospheric processes has increased dramatically since the 19th century with important advances in observational techniques and global monitoring, numerical modeling as well as weather, climate and air quality forecasting. Efforts continue around the questions of atmospheric and climate predictability as well as the combined role of dynamical, physical and chemical processes from the lower to the upper atmosphere. The present paper will provide an historical perspective on the progress made during the last two centuries and highlight by some specific examples our ability to treat today complex questions related to the Earth system. The response of the atmospheric chemical system to the slowdown of the world economy during the COVID-19 pandemic will be presented to illustrate our current modeling and observational capability.*

In Highlight Talk H3-715, Guy Brasseur presented progress and challenges in atmospheric sciences, which split the discussion between the weather, the climate and air quality.

The presentation first discussed how the atmosphere, the solid earth and the oceans interact to form a complex, interrelated system that cannot be disentangled, and how space instrumentation monitoring of the geosphere is supporting advancement in earth sciences. However, contributions are also being made possible through the construction of mathematical models to unravel the complexity of the earth system. The presentation then focused on the current scientific and operational capabilities and challenges for the prediction of the weather, the climate and air quality, before delving into the challenges ahead.

On the aspect of the weather and how to forecast it, it all comes down to an initial value problem that we need to solve. From Newton's law in the 17th century to Vilhelm Bjerknes at the beginning of the 20th century, predictive skills have greatly advanced, and they have been based on the laws of physics. Bjerknes suggested that the problem is deterministic and can be solved with fluid equations. Before the computer age, Lewis Fry Richardson manually predicted the weather for Great Britain and postulated that 64 000 persons would be needed for a global prediction. This proposal, however, was superseded with the invention of computers and thus the coming of a new era. It was understood during this time that the atmosphere is a chaotic system, and its predictability was thus limited. Ensemble predictions were then performed to overcome these limits. Based on this knowledge, Edward Lorenz developed in 1963 a simplified model for atmospheric convection, which illustrated how slight changes in initial conditions can strongly affect the solutions of the system. However, over the last 40 years, predictive skills have increased by improving the representation of unresolved processes in models (parameterization of cloud and precipitation physics, formulation of radiative transfer), introducing ensemble methods to produce forecast uncertainty estimates, introducing objective analysis techniques to include information from observations, and the assimilation of meteorological conditions. Predicting the weather over time, and particularly beyond two weeks, remains challenging, but high accuracy has been attained for shorter periods.

Climate prediction is a forced boundary condition. Over a hundred years ago, Svante Arrhenius already quantified changes in surface temperature due to the increase of CO_2 levels. Norma Philipps developed the first Global Circulation Model in 1956, while early climate models were being developed. We cannot predict the future state of the atmosphere on decadal to century timescales, but we can perform an ensemble of simulations (many realizations) and derive the change in the probability distribution of climate states. Thus, we can project the evolution of statistical moments like the mean and variance of climate variables such as the temperature for different scenarios of greenhouse gas emissions and thus extract future scenarios with their corresponding uncertainties. This is the approach followed by the Intergovernmental Panel on Climate Change (IPCC) looking at the future evolution of the climate as a function of greenhouse gas emissions.

Air quality is another area of concern for mankind, with potentially catastrophic consequences. As for its predictability, this becomes a multiscale problem that requires more active research and multi-technology observations. Similar to the weather and climate, simplified models help to advance our understanding of air quality, but they require ground truth to be validated. In that sense, the COVID-19 pandemic offered a global unplanned chemistry experiment, with various lockdowns in different regions of the world at different periods, which acted as proxies for attempts to clean up the atmosphere from its pollutants. This global experiment essentially created a wide range of changes in atmospheric chemistry, whose impacts are being analysed by the atmospheric science community. Some results are not linear. For example, while a reduction of NO_x emission was observed, in very polluted areas it actually led to an increase of the surface ozone concentration. In the upper atmosphere, an anomaly in the meteorological conditions and the Arctic ozone hole influenced the developments. The outcome of this experiment will help to advance air quality predictions and has the potential to shape future science-based policies towards better air quality.

What then can be expected from atmospheric science in the future? The predictability of the weather, climate and air quality remains a very active field of research with large efforts, on one hand, to expand climate predictions to seasonal and decadal scales of fluctuations in the atmospheric circulation, such as the North Atlantic Oscillation, and on the other hand, to develop high resolution representations of the atmosphere. The field of machine learning enables breakthroughs in the detection and analysis of complex relationships and patterns in large multivariate data sets. Such advances will pave the way for possible climate intervention as an alternative to reducing emissions and adapting our way of life to limit the impact on the climate.

The Highlight Talk further illustrated the current level of predictions and common challenges faced by the weather forecasting, climate prediction and air quality monitoring communities as well as the verification regime community, as knowledge of the atmosphere has a direct impact on the accuracy of the analysis and simulations needed for radionuclide and infrasound technologies, and for ATM. Just as the goal of the CTBTO is to advance the fusion of technologies, the need to improve atmospheric prediction capabilities likely requires the integration of all three components: atmospheric composition, weather and climate.

5 Panel Discussions

5. Panel Discussions

5.1. J03 – Lessons from Historical Nuclear Test Explosions and Value of Recorded Signals for Monitoring Science

Moderator: Rong-Song Jih[1]
Panellists: David Bowers[2]; Inna Sokolova[3]; Lars Ceranna[4]; Paul G. Richards[5]; Xiaoming Wang[6]; Yurii Dubasov[7]
[1]*US Department of State, USA*
[2]*AWE Blacknest, Reading, United Kingdom*
[3]*Institute of Geophysical Research, Almaty, Kazakhstan*
[4]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
[5]*Lamont-Doherty Earth Observatory of Columbia University, New York, NY, USA*
[6]*CTBT Beijing National Data Center and Beijing Radionuclide Laboratory, Beijing, China*
[7]*Khlopin Radium Institute, St. Petersburg, Russian Federation*
Abstract: *The nuclear tests announced by the DPRK provided an opportunity to test methods and gain experience with respect to the estimation of the absolute and relative event location, depth and magnitude. However, this experience is limited to one specific test location. Much broader experience can be gained by applying modern analysis methods to the vast amount of data recorded on more than 2000 historic nuclear test explosions. To support such developments, valuable progress towards preserving and making available for research digitized data of historic nuclear explosions has been made. The goal of this session is to identify the priorities for continuing and expanding these efforts. Historic data are needed from as many as possible different regions and geological characteristics. Signals should be preserved from tests in the atmosphere, underwater and underground. While most ongoing efforts focus on seismic data, the historic hydroacoustic and infrasound data are rare and radionuclide data are sparse.*

The treasure of historical observations associated with nuclear test explosions is of great value for realistic case studies to validate methods, with the objective of identifying the source of an event that is of relevance for Treaty monitoring. These data can also be used to identify challenges in nuclear explosion monitoring and for training and NDC performance exercises. Not all relevant data are available, and there are challenges in their preservation and use.

Panel discussion J03 was moderated by Rong-Song Jih, who emphasized the need to identify priorities and digitize all relevant available data sets. Region specific geophysical calibration needs to be taken into consideration. Historical controlled active source experiments and passive deployments will support this. The US Department of State supports and funds such activities for data preservation and conversion into digital format. Data have to be disseminated and thoroughly analysed. Successful cases from Kazakhstan, Tajikistan and other countries were presented. A new joint study on the announced nuclear test explosions by the Democratic People's Republic of Korea was also discussed. Data are shared to enhance analysis.

Paul Richards noted that seismology is an observational science. Scanning and digitizing historical data, especially in unique cases, is important, not only for the reprocessing of historical cases but also for future analysis. He emphasized that the monitoring community should not lose any historical data. For example, more than 850 nuclear tests were conducted by the United States during the pre-digital era, and only hard copy seismograms are available. Seismograms from the very first eight nuclear tests were presented. The first event, Trinity, was measured at many stations, and seismic and infrasound waves from the station Tucson (Arizona) were shown. Interestingly, there was a chemical explosion 10 weeks before Trinity. This allows the application of modern techniques such as waveform cross-correlation comparison to obtain new information, e.g. the Trinity origin time, which was not accurately determined. Fifteen years after Trinity, a global seismological network was ready to measure the largest event ever: the 50 Mt Tzar Bomba, with astounding infrasound signals travelling over the globe. There are many modern analysis tasks that can be addressed using historical data. For example, improvement in small events monitoring can be achieved, and better understanding of the global picture can be obtained by studying bigger events. Both directions are important and should be investigated. In any case, all data should be made available to the monitoring community.

David Bowers described the history of Atomic Weapons Establishment (AWE) Blacknest, which started in 1958 at the time of the Geneva negotiations. Seismology was the leading technology in the identification of underground nuclear tests, and new approaches to measurements and data collection and archiving were developed. A related research group started in 1959. Seismic array stations were designed by radar engineers to suppress noise. The cross-array design was successful and likely used in other countries, e.g. the Borovoye array in Kazakhstan. The original array stations in the United Kingdom are now an important part of the IMS. The beam-forming technique applied to seismic antennas enhanced data processing and seismic monitoring capabilities. Measurements during earlier years showed that the monitoring network could consist of hundreds of stations due to successful measurements at far regional stations, instead of the thousands of near-regional stations that were initially estimated to be required for detection of ~1 kt class tests. The magnetic tapes that were used for data storage are now fully preserved in modern formats and digital data archives.

Lars Ceranna addressed several principal questions of the session. First, the multi-technology analysis of the announced nuclear test by the Democratic People's Republic of Korea in 2017 was presented in a style similar to the expert technical analysis formulated in the CTBT. There was extensive analysis of various data. Teleseismic and regional wave propagation were calculated, and moment tensor simulation revealed an explosion-like solution for the mainshock and an implosion-like source function of the first aftershock indicating the cavity collapse. The relative location based on IMS and non-IMS data was found to match the information from the Democratic People's Republic of Korea, and large surface deformations were estimated by satellite interferometry. The question of why no radionuclides were found after several of the announced tests was addressed. Radioactive noble gas signals were detected for four out of the six tests, with two 'smoking gun' measurements and two signals found later by applying more complex methods based on ATM. Using non-IMS data as a supplement to monitoring technologies was also discussed. The Differential Interferometric Synthetic Aperture Radar (DInSAR) images of the Nevada Test Site craters are helpful for the interpretation of cratering and surface deformation observed in various places. Seismic data sets from >10 000 three component stations worldwide are freely available and can be used to enhance data processing and obtain more accurate and reliable results. Several examples were given to demonstrate the surface subsidence using images from the Nevada Test Site, to show radionuclide fingerprints of atmospheric explosions and to highlight the analysis of the Beirut explosion, with yield estimates of ~1 kt.

Inna Sokolova described the successful recovery of analog and digital data from Soviet era networks. These data sets were almost lost, as the hard copy seismograms in many places, e.g. Garm, Tajikistan, were damaged. The city of Talgar, Kazakhstan, was the centre of the Complex Seismological Expedition (CSE). The CSE has a large archive of paper and digital records that had been moved between various State organizations of Kazakhstan. As a result, the unprotected archive was damaged. Since 2018, the archive has remained in one place but has not been used. Currently, the data, which include regional measurements from the Semipalatinsk and Lop Nor test sites, are digitized and used in various applications, e.g. the travel time and amplitude curves, as well as for seismic discrimination. Young seismologists have a rare opportunity to work with this unique data set. She suggested that scanning and digitization software should be included in NDC in a box.

Xiaoming Wang described the experience of the Chinese NDC. The work of the IMS has been improving with time, and the current station certification status is above 90 per cent. New processing methods involving machine learning and artificial intelligence are routinely used. The new processing methods should be developed and improved using historical data, which have to be carefully recovered, saved and then studied. This is a potential task for the IMS and IDC to improve standards of processing with robust station parameters with appropriate quality control, accuracy and quality of event bulletins. It was suggested that historical data be made available through vDEC. Blockchain was mentioned as a new technology to provide data authentication.

The panellists addressed the following questions from the audience:

What is the biggest challenge to data rescue?

Paul Richards: Different countries have different ways to address this issue. Some countries have to resolve many problems, as described by Inna Sokolova. Some countries ignore this problem. Four aspects should be considered: (1) understanding what data is available in a given country and what data can be retrieved and used, (2) data scanning or scanning/digitizing, (3) metadata and (4) delivery to the broader community.
Rong-Song Jih: Digitization is a challenge, and specialized software has to be used to resolve contradictions. Sharing experience with different partners facing the same challenges, such as data specialists at the Library of Congress in the United States, may be useful.

David Bowers: Magnetic tapes rescue is a challenge due to record degradation and the deterioration of physical condition. Water makes the tapes sticky. Demodulation was done by hardware, and the problem has historical roots. This problem was resolved in 2007 by a new eight channel chip. It was found that downsampling to 100 Hz may improve the dynamic resolution to 25 bits.
Lars Ceranna: Grafenberg data are all in modern archive and fully available. The Federal Institute for Geosciences and Natural Resources (Germany) saved data from the historical tapes. More effort will be needed to save old carbon black recordings.

Should we store the historical digitized data and metadata in one repository and follow one digitization procedure for everyone? Can the PTS/IDC coordinate and promote a data rescue and digitization programme?

Rong-Song Jih: Yes and no. Many institutions are involved and use the same methods. At the same time, the data diversity is extremely large, and specific methods are developed to address difficult challenges. It is likely premature to unify and standardize the methods.
David Bowers: Quality assurance and quality control of data and metadata are required. The approach should be flexible, like the three stage approach at AWE Blacknest.
Lars Ceranna: European countries have such a tool implemented. Where to store data is less important than data accessibility. The PTS may lead this process, and we can discuss it in the future.

How should the calibration of old instruments be established? How should all data be re-archived when archiving technology is changing?

Rong-Song Jih: Michigan State University (United States) helps some Asian institutions to recover the calibration.

Lars Ceranna: We re-archive data continuously. This is the lesson learned. It saves time and money and keeps the data available.
David Bowers: The usefulness of the historical data is an issue due to the different technical conditions of how the explosion was conducted. This should be kept in mind.
Paul Richards: Calibration through known event mechanisms is one of the ways to recover the unknown responses. For a good event, the comparison of records obtained by instruments with known and unknown responses helps to understand the unknown response.

5.2. J04 – Innovation Affecting CTBT: International Monitoring System (IMS Sensors)

Moderator: Nurcan Meral Özel[1]
Panellists: Geoffrey Cram[2]; Guilhem Douysset[3]; Roger Waxler[4]; Shuichi Kodaira[5]; Thomas Bruns[6]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*University of Washington Seattle, WA, USA*
[3]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[4]*National Center for Physical Acoustics, University of Mississippi, MS, USA*
[5]*Japan Agency for Marine-Earth Science and Technology, Yokosuka, Kanagawa, Japan*
[6]*Physikalisch-Technische Bundesanstalt, Germany*
Corresponding Author: nurcan.meral.ozel@ctbto.org
Abstract: *The CTBT IMS employs four monitoring technologies: seismology, infrasound, hydroacoustics and radionuclide (both particulate and noble gas). It is vital that the PTS stays abreast of new developments related to all sensor types to maintain its high-performance level, and network sustainability, in order to safeguard and improve the Treaty Verification capability. This panel will discuss new generation sensors that may already be available, and innovative efforts for future developments. Potential areas of discussion are networks of infrasound sensors, combination of rotational and directional seismic sensors, modular design hydroacoustic hydrophone stations, SMART underwater cables and sensors, fibre-optic seismometers and hydrophones, improved concepts for particulate radionuclide stations, new generation of noble gas stations.*

Panel J04 discussed sensor innovation in all technologies that might be relevant for the IMS. It started with Shuichi Kodaira, who described the seismic monitoring of active regions near Japan. The Japan Trench subduction zone was the location of the M9 Tohoku-oki earthquake in 2011. The earthquake, which occurred along the northeastern coast of Japan, caused tsunami waves of more than 30 m. In that area, the S-net is a large scale seafloor observatory network that was constructed as part of an early warning system. It now consists of 150 monitoring components based on cable embedded seismometers and pressure sensors. To the south, the Dense Ocean floor Network System for Earthquakes and Tsunamis (DONET), comprising 51 stations of node connected seismometers, pressure sensors and hydrophones, monitors the Nankai Trough. It was developed by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and is operated by the National Research Institute for Earth Science and Disaster Resilience (NIED). The modular network design emphasizes reliability, redundancy and sustainability, with components that are easy to maintain and replace.

The great potential for fibre-optic technologies, including shallow borehole optical tiltmeters, fibre-optic strain sensors and distributed acoustic sensing (DAS), was emphasized. There are plans to expand upon the DONET cable system, installing borehole observatories, calibrating all DONET sensors to utilize them as pressure sensors, and developing fibre-optic sensors to connect to the DONET network. In addition, it was noted that three dimensional seismogenic zone models are necessary to transform measured deformations into mapping of plate

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

boundary slips. Velocity and plate geometry modelling is done by smoothly interpolating two dimensional profiles with 30 km spacing.

Roger Waxler described ongoing projects at the National Center for Physical Acoustics (NCPA) at the University of Mississippi in the United States. Research areas at NCPA include T sensor design and calibration, propagation models (open source package), array signal processing (large-N, real time data analysis) and wind noise, which constitutes a major problem for infrasound sensors. It was noted that wind noise reducing manifolds provide ~20 dB signal enhancement, but this is not sufficient in windy environments.

Important developments in infrasound sensors over the last decade were highlighted. High fidelity sensors that are stable, low noise and have low seismic sensitivity are currently available. Calibration is reaching maturity: international standards are now under development, and in situ calibration is becoming standardized.

The presentation made the following recommendations:

- Use large-N arrays for wind noise mitigation (three to four years away). Replace single sensors with arrays and use advanced signal processing (potentially to do better than 1/sqrt(N) dependence). The current development of low cost/low power sensors can assist in the implementation of such arrays.
- Emphasize the topic of calibration.
- Increase the use of auxiliary stations, noting that the IMS network is sparse (on average 2000 km between stations) and infrasound signal is directional because of the wind.
- Add realistic propagation modelling capability. User friendly and fast packages using basic algorithms and parallel processing are under rapid development. The science of atmospheric profiling is also under rapid development.
- Incorporate probabilistic uncertainties in modelling and geolocation. Rigorous connection to empirical statistical models is critical.

Thomas Bruns from PTB National Metrology Institute (Germany) explained the realization and dissemination of the SI unit system and gave as examples the definitions of units for mass and time. Traceability by national calibration hierarchy, quality assurance and monitoring by comparison measurements is important. It was noted that mutual recognition acceptance is handled under a framework of the International Committee for Weights and Measures (CIPM MRA) (https://www.bipm.org/en/cipm-mra). There is a practical arrangement between the Bureau of the International Committee for Weights and Measures (BIPM, Paris) and the CTBTO following CIPM Decision CIPM/108-38 of October 2019. The PTB performs a research project for CTBTO, Infra AUV, and succeeded only recently to reach 10 mHz (www.ptb.de/empir2020/infra-auv/home/).

A proposal was made to advance the traceability of the IMS sensors to the SI system and the CIPM MRA. In his concluding remarks, Thomas Bruns echoed the call to use large-N sensor arrays and to develop sensor and data fusion. In addition, the need for proper calibration and propagation of errors methodology was emphasized.

Geoffrey Cram of the Applied Physics Laboratory of the University of Washington (United States) noted that work with the US Navy comprises 40 to 50 per cent of the laboratory's budget. He described the use of two long cables that stretch into the Pacific Ocean with 140 nodes of scientific instruments. Geodetic research is being carried out where measuring sea floor movements is based on pressure sensors. To fight sensor drifts, a possibility of calibration with signals from shore was developed, with millimetre to centimetre accuracy at 3000 m depth. The range is now 50 km and may increase to 100 km. Tilt can be measured with three axis accelerometer resolution microradians.

He also expressed great interest in distributed acoustic sensing. Reflections of laser light (such as Rayleigh backscattering) transmit information on physical conditions such as temperature and strain (0.005 C resolution, 1–20 m, 100–1000s Hz). Various acronyms are used: DOFS, DAS, DVS, DRS. In IMS hydroacoustic triplets, the cable between the shore and the first node (21–215 km) contains optical fibres and can be used for sensing seismic signals, but also temperature and strain. The use of fibres between the nodes can also be considered.

In conclusion, he stated that the presentation of Shuichi Kodaira made a good case for distributed sensing, noting that there are cables begging the scientific community to use them.

Guilhem Douysset of the Commissariat à l'énergie atomique et aux énergies alternatives (CEA) presented current developments and future directions in radionuclide detection technology. There are now several new noble gas measurement systems with improved detection capability that will be installed in the IMS in the near future: SPALAX NG, SAUNA III, MIKS and Xenon International. The deployment of the new systems into the IMS will take place over the next 15 to 20 years, resulting in much improved sensitivity for the detection of xenon isotopes. Future improvements to these systems are likely to focus on reducing electricity consumption and footprint while preserving or improving performance. After entry into force, the Conference of the States Parties may consider increasing the number of noble gas stations from 40 to 80, which would greatly improve Treaty verification capability.

The global background of xenon isotopes has been found to be higher than what was expected 25 years ago, mainly due to xenon emissions from medical isotope production. While isotope ratios in the background are generally different from those associated with a nuclear explosion, uncertainties in the interpretation of IMS measurements remain. Being able to identify the source of civil xenon emissions would increase the robustness of verification. Therefore a project involving voluntary notification and stack monitoring to assist in better understanding IMS detections has been established.

The technology used for the collection of particulate radioactivity is well established and robust, but no further increase in sensitivity is possible by increasing air volume without a technology change. Electrostatic collection is a technology that promises to increase air volume while reducing power consumption and could be a future technology for particulate stations of the IMS.

Improvements in particulate radionuclide detection sensitivity are possible by gamma–gamma coincidence detection. Samples are sandwiched between two high purity germanium (HPGe) detectors, and signals are analysed for detections in coincidence in both detectors. The technology has been shown to achieve a tenfold improvement in sensitivity for some isotopes. As the atmospheric background for many particulate isotopes is very low, this would greatly enhance sensitivity for detecting Treaty violations.

In a concluding remark, Giulhem Douysset emphasized the need for robustness of IMS equipment.

5.3. J05 – Innovation Affecting CTBT: IDC Data Analysis (Needs, Ideas and Implementation Pathways)

Moderator: Megan Slinkard[1]
Panellists: Claire Labonne[2]; Harry Miley[3]; Hua Li[4]; Nimar Arora[5]; Stephen Myers[6]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[3]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
[4]*Chinese Academy of Engineering Physics, China*
[5]*Bayesian Logic, Inc., CA, USA*
[6]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: megan.slinkard@ctbto.org
Abstract: *The purpose of this panel is to generate discussion about how data and data analysis approaches can improve IDC processing, and how to go about introducing new approaches at the IDC. It will leave participants with a better understanding of where data analysis improvements are still desired by the PTS, what new tools are emerging which might be intriguing to apply to our scenarios, where new analysis approaches have made a big difference, and how things need to be tested in order to facilitate ease of acceptance at the IDC. Themes in data analysis include moving from parameters to full waveform, using machine learning and pattern-recognizing approaches, and improving understanding of uncertainties. Discussion will include focus on these themes, and also on data-fusion applications, new pipeline paradigms, and cases where improvements in multiple areas may have non-linear improvements.*

The goal of panel J05 was to generate discussion about how data and data analysis approaches can improve IDC processing, as well as how to introduce new approaches at the IDC. Participants reflected on where data analysis improvements are still desired by the PTS, where new analysis approaches have already made a big difference, how things need to be tested, and what new tools are emerging that might be interesting to apply to CTBT scenarios.

To begin, the panellists were asked to discuss improvements to data analysis that have already led to significant gains.

Harry Miley reviewed progress in radionuclide detection and processing since the beginning of his career. He recalled a time when there might be a single detection at a single station and all knowledge had to be obtained by looking at the isotopic ratios from that one detection. Now, oftentimes the community uses xenon samples and, in a huge step forward, can use the collection of both detections and non-detections to make probability distributions for the original location. After determining an initial location estimate, it is now possible to undertake backtracking for each sample and calculate release magnitudes and release times. Release times are now calculated on the order of three hour periods, rather than a day.

Stephen Myers reviewed progress in seismic, hydroacoustic and infrasound monitoring and improvements to various stages of the processing pipeline, including improvements to the regional seismic travel time (RSTT) model, which improves travel time estimation for regional signals. This in turn improves location estimates for events that include both teleseismic and regional waveforms. He also discussed current research topics, such as moving from conventional filtering to wavelet filtering, which improves detection and determination of arrival times; using machine learning to estimate models, such as atmospheric transport and seismic travel times, which provides estimates much more quickly than the full mathematical calculation; and using neural networks to categorize detections.

Claire Labonne discussed new ways to improve processing, such as arrays made from 3-C sensors. Another emerging idea is to improve waveform quality by using principal component analysis (PCA) to separate noise and signal. Tools from multi-source processing could also be used to separate sources.

Nimar Arora shared the Bayesian model work he has done in partnership with the IDC and demonstrated that these approaches can generate results comparable to that of human analysts. He also discussed current advances in deep learning, which often, but not always, is applicable to the CTBTO. However, it was noted that much current work is focused on regional distances, not teleseismic as is needed by the CTBTO.

The panellists were then asked about where there is room for improvement.

Harry Miley identified four key questions that still need to be answered in the radionuclide domain: (1) How do we fuse measurements of xenon and aerosols, which behave quite differently in the atmosphere? (2) How do we take the radionuclide background into account? (3) How do we make use of isotopic ratios, for example in a screening tool? and (4) How can we automatically generate a list of associated measurements? How do we do the equivalent of waveform association?

Stephen Myers first emphasized that the CTBTO has very robust waveform processing and encouraged early career researchers to review IDC documentation and methods that were presented at previous SnT conferences and workshops to understand the current system. Nevertheless, there is still a need to improve the accuracy and efficiency of measurements of incoming signals and to improve the matching of those observations to what is predicted in models. This entails improving the models and making them usable in an operational system (e.g. fast). He encouraged researchers to remember that new approaches need thorough testing, and tools need to work continuously and not only under ideal conditions.

Claire Labonne explored what makes CTBTO data difficult. She mentioned the gap between theory and real life, and the challenges real data often pose. As an example, she discussed the challenges of identifying S waves. She noted that there is still a need to improve the measurement aspects of waveforms and correctly identify phases.

A question from the audience built on these reflections and asked how to account for true information content in data rather than 'red herrings' (e.g. distractions and misleading data). Nimar Arora recounted a situation where he originally found that dropping some data helped results, but exploring the 'whys' of that led to a better understanding of the physics and improved his model. Once the model was improved, including all the data improved results. He emphasized that at some level, red herring data means we do not fully understand things.

The conversation shifted to the testing of analysis tools, including what testing is needed, how to test robustly, and when the community can be assured that a new approach is ready for operational use. Nimar Arora shared his experience with NET-VISA and discussed the benefits of receiving critical questions from the CTBTO community. He mentioned how more testing often leads to more questions, which leads to improvements, and then more testing. For NET-VISA, it has been a many years long testing process. Megan Slinkard discussed how during the testing process for NET-VISA the IDC learned as well, and refined and clarified its testing needs. Now the list of required tests for new approaches is much clearer. Stephen Myers further emphasized that methods introduced need to be very robust and work on all data (not only well-curated test data) and be transparent so that all States Signatories can understand it.

A comment from the audience highlighted the importance of uncertainty measurements and the challenge of a lack of

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

training data showing nuclear explosions. There was consensus amongst the panellists that improving uncertainty estimates would be of tremendous value. Multiple questions related to this topic were posed. One was how to validate methods without ground truth events. Nimar Arora mentioned how he had learned, from a presentation Stephen Myers gave many years ago, to compare results from the relatively sparse IMS network with results from dense local networks. Stephen Myers expressed appreciation for the International Seismological Centre (ISC) and its good work collecting and sharing data. Researchers were also reminded to be very careful testing on synthetic data, with some stories shared of when that gave unrealistically good results.

The discussion returned to the journey of integrating new methods into the IDC processing pipeline. Nimar Arora outlined the NET-VISA journey, and how in later years more and more of the testing was undertaken by the IDC. He also mentioned some new research that is in the process of being integrated into NET-VISA and thus will be able to be tested much more quickly than expected. Stephen Myers outlined the RSTT journey. It also took about a decade to go through the process from idea to implementation. The IDC and many NDCs were very active in testing and made robust contributions that led to significant improvements, particularly in the uncertainty model.

The session closed with each panellist sharing 30 seconds of advice or key points to remember. Researchers were encouraged to: (1) find a champion at the IDC to help guide their research through the testing process, (2) focus radionuclide research on where the current pipeline ends, (3) not forget that we can integrate over the counter components and (4) remember that there are so many things that could be done, but to find the best problems it is good to first familiarize oneself with the current IDC processing system and then look for areas to contribute.

5.4 Introductory Talks to Panel J06

Panel J06 was preceded by two Introductory Talks: I06-721 by Zeinabou Mindaoudou Souley and I06-719 by Öcal Necmioğlu.

5.4.1 I06-721 – Civil and Scientific Applications of IMS Data

Speaker: Zeinabou Mindaoudou Souley[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Abstract: *Although the main purpose of the International Monitoring System (IMS) is nuclear explosion monitoring, this unique asset of available global data may also be used for scientific and civil purposes. Scientific applications follow the decision of the CTBTO PrepCom from November 2000, in which it was stated that the PTS may provide IMS data and IDC products to organizations for the purpose of conducting research associated with the development of the IMS and IDC. Since 2011, the virtual Data Exploitation Centre (vDEC) has allowed scientists and researchers access to the CTBT's IMS data. Following the Sumatra earthquake on 26 December 2004, it was decided that national and regional tsunami warning centres recognized by IOC/UNESCO can sign an arrangement with the CTBTO to receive IMS data for tsunami early warning. After the Fukushima Daiichi nuclear power plant accident, the CTBTO became a member of the Inter-Agency Committee on Radiological and Nuclear Emergencies (IACRNE). Further civil applications for disaster risk reduction have been proposed. This presentation reviews the progress on civil and scientific applications made in the 25 years since the opening of the CTBT for signature.*

Zeinabou Mindaoudou, Director of the IDC, opened Invited Talk I06-721 on the civil and scientific applications of IMS data by emphasizing that the primary purpose of the CTBT verification regime is to verify compliance with the Treaty. However, she also noted that the Treaty explicitly states that the States Parties may benefit from using IMS data, which are a tremendous asset, for peaceful and scientific purposes.

The Preparatory Commission has defined the rules and procedures for data sharing. The main category of those who have access to IMS data is authorized users, comprising those designated by States Signatories to use IMS data and IDC products for nuclear explosion monitoring. In addition, the Preparatory Commission has decided to provide data for two specific civil applications: tsunami warning and radiological and nuclear emergencies, and has given permission to the PTS to share IMS data for scientific applications under confidentiality agreements.

The Fukushima Daiichi nuclear power plant accident in 2011 served as an example to demonstrate the importance of IMS data. IMS observations of released radioactivity were shared immediately with the IAEA and the WMO. One year later, in 2012, the CTBTO joined the Inter-Agency Committee on Radiological and Nuclear Emergencies (IACRNE).

Hydroacoustic data together with seismic data form the basis for tsunami early warning. In the framework of an agreement with the United Nations Educational, Scientific and Cultural Organization (UNESCO), the PTS provides data to 18 national or regional tsunami warning centres that are recognized by the Intergovernmental Oceanographic Commission of UNESCO. It was also mentioned that IMS data observe signals of many more events that have the potential for civil applications. For example, infrasound observations are useful for the purposes of monitoring chemical explosions near to the earth's surface, detecting and locating meteorite impacts, tracking storms, and providing early warning about volcanic ash plumes in collaboration with the International Civil Aviation Organization and Volcanic Ash Advisory Centers.

The principles of access to IMS data for scientific applications using vDEC were explained. Applications to use vDEC can be submitted via the homepage http://www.ctbto.org/specials/vdec. Each technology has a fair share of users (seismic: 22.5 per cent, hydroacoustic: 29.5 per cent, infrasound: 7.5 per cent, radionuclide: 29 per cent). In addition, it is interesting to note that about 12 per cent of all vDEC projects make use of more than one sensor technology. Examples were provided of various projects that use data from each single technology, as well as from multiple technologies, taking advantage of the synergy between them.

Examples for the use of hydroacoustic data through the vDEC platform include studies of inter-annual and seasonal occurrences of blue whales and fin whales at middle and low latitudes in the Southern Hemisphere, the impact of shipping noise on baleen whales, and submarine volcanic activity. Other civil applications include searching for signals associated with the missing Malaysian airliner MH370 and the missing Argentine submarine *ARA San Juan*.

Examples for the use of radionuclide data through the vDEC platform include the study of atmospheric behaviour, deposition and source strength of radioactive materials from the Fukushima Daiichi nuclear power plant accident. Beryllium-7, with a short half-life of 53 days, is used as a tracer for various atmospheric processes. Uncertainties of global ATM of radionuclides are quantified. ATM Challenges are used to ascertain the level of agreement one can achieve between simulated concentrations and IMS measurements using stack emission data and an atmospheric transport model.

The presentation emphasized the importance of the strong relationship between the scientific and technological community and the CTBTO as a way to ensure that the IMS remains at the forefront of technological innovation and that no nuclear explosion will go undetected. A striking example is related to the announced nuclear tests by the Democratic People's Republic of Korea. Scientists are studying the characteristics of the depths of the source in order to improve Treaty monitoring methods based on moment tensor analysis or cross-correlation. With civil applications of IMS data, there is definitely potential for more applications beyond tsunami early warning and international cooperation in the event of nuclear and radiological emergencies.

5.4.2 I06-719 – Sustainable Development, Disaster Risk Reduction and the CTBTO Verification Regime

Speaker: Öcal Necmioğlu[1]
[1]*Bogazici University, Istanbul, Turkey*
Corresponding Author: ocal.necmioglu@boun.edu.tr
Abstract: *Natural disasters are increasing in frequency and intensity, becoming extreme and complex and have been affecting many countries over recent years. The UN 2030 Agenda for Sustainable Development recognizes and reaffirms the urgent need to reduce the risk of disasters. The need for modern, multi-hazard disaster response systems to strengthen the national and collective ability to prevent and prepare for emergencies is evident. Early warning is a major component of disaster risk reduction with the potential to prevent loss of life and reduce the economic and material impacts of disasters. The Sendai Framework for Disaster Risk Reduction 2015-2030 recognizes the benefits of multi-hazard early warnings systems and places them in one of its seven global targets. Noting that approximately 2.5 billion USD has been invested in the CTBT Verification Regime so far, the recognition and promotion of the civil and scientific use of its data, ranging from tsunami warning to volcano monitoring, from climate change to better understanding of the ocean processes and marine life, is critical to maintain Member State and public interest and investment in this state-of-art system, even beyond Entry Into Force of the CTBT, also to preserve national CTBT verification capacity in a sustainable manner.*

In Invited Talk I06-719, Öcal Necmioğlu shared various examples of civil and scientific uses of IMS data to emphasize the capability of the IMS and highlight the significant progress achieved during the last decades. In particular, he noted the fact that almost 90 per cent of the network foreseen by the Treaty has been certified. This achievement was possible thanks to extensive collaboration between the States Signatories and the PTS.

The Indian Ocean tsunami in 2004 was a milestone for the PTS in terms of sharing IMS data with tsunami warning centres under an agreement with UNESCO. This collaboration also opened the door to other scientific work that is not directly related to the CTBT. The second milestone was the volcanic eruptions of Eyjafjallajökull in Iceland in 2010, which led to the establishment of a volcanic information system that uses infrasound data. Other events, such as the Fukushima Daiichi nuclear power plant accident, further demonstrated IMS capabilities and intensified cooperation with international organizations like the WMO, the World Health Organization (WHO) and the IAEA.

The aims of the Sendai Framework for Disaster Risk Reduction 2015–2030 were presented, with a special emphasis on the objective of increasing access to multi-hazard early warning systems and disaster risk information and assessments by 2030.

To conclude, it was observed that what is considered 'noise' from the CTBT perspective is actually an interesting signal for many other contexts. Ultimately, studying the noise in all technologies of the verification regime in detail assures better classification of signals relevant to the CTBT.

5.5. J06 – Panel on Civil and Scientific Applications: Prospects

Moderators: Georgios Haralabus[1]; Jolanta Kusmierczyk-Michulec[1]
Panellists: Alexandra Iezzi[2]; Christian Maurer[3]; Mohamed Nabil Mohamed ElGabry[4]; Öcal Necmioğlu[5]; Wenbo Wu[6]; Xyoli Pérez-Campos[7]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*University of California, Santa Barbara, CA, USA*
[3]*Central Institution for Meteorology and Geodynamics (ZAMG), Vienna, Austria*
[4]*National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Egypt*
[5]*Bogazici University, Istanbul, Turkey*
[6]*California Institute of Technology, CA, USA*
[7]*National Seismological Service, Mexico*
Abstract: *The data recorded by CTBT's International Monitoring System constitute a unique trove of knowledge with a broad range of civil and scientific applications. In the last decade, thanks to the establishment of the virtual Data Exploitation Centre (vDEC), it became possible for international experts to have access to these data to conduct research and to publish new findings, while the organization would gain from the knowledge transfer and interaction between internal and external experts. The list of possible applications that exploit CTBT data is long and includes e.g. scientific studies on bolides, marine mammal migration studies, discrimination between earthquakes and man-made events, investigation of the Earth's interior, investigation of source depth characteristics from large explosions or validation of atmospheric transport modelling. It includes as well civil applications, such as contribution to tsunami warning centres, the impact of ocean noise on whales, ocean thermometry and climate change.*

Panel J06 was moderated by Georgios Haralabus and Jolanta Kusmierczyk-Michulec of the PTS. The panellists emphasized the uniqueness of IMS data, especially in terms of common high standards for a global network, global coverage and tremendous value as a compilation of over 20 years of archive data from sensors, the majority of which have remained in the same site. The panellists shared examples of work that would not be possible without IMS data.

Xyoli Pérez-Campos presented the application of IMS seismic and hydroacoustic data in regional earthquake monitoring in Mexico. Hydroacoustic station HA6 in Socorro Island is located 200 km from the active Rivera Fracture Zone and helped in the location of 93 events 4≤M≤6.4 in the period 2004–2021. It was emphasized that IMS stations either compliment national networks or constitute the backbone of the monitoring network in many countries.

Christian Maurer discussed large to mesoscale ATM using the FLEXPART model for the monitoring of volcanic emissions and radionuclide emissions. The high standards of IMS data, which provide global coverage, date–time stamps and information on the start and stop of collection times, was emphasized. Furthermore, it was noted that IMS radionuclide data allow for the organization of international ATM Challenge exercises, the ultimate goal of which is to be able to discriminate between CTBT-relevant events and the local background.

Wenbo Wu presented an example of the application of hydroacoustic data for work towards the development of global ocean acoustic thermometry. This is an important question in the context of global warming. The described research uses hydrophone signals from earthquakes to measure ocean temperature changes, based on the dependence of sound speed on water temperature. The results show how a 0.2 s travel time anomaly is translated into an estimate of 0.04 degree warming in the Indian Ocean. The coverage of IMS stations will help to deduce such estimates globally. This will be assisted by opportunities from drifting autonomous hydrophones and distributed acoustic sensing. The possibility of using the cables connected to IMS hydrophones as a means for additional sensing technologies was also suggested.

Alexandra Iezzi presented the application of IMS infrasound data to monitor volcanic eruptions, i.e. to detect, locate and quantify volcanic eruptions. In general, infrasound data can help to deepen knowledge related to volcanic eruptions. The propagation path of long range infrasound signals is highly influenced by atmospheric conditions such as wind and temperature, which can enhance or diminish signals and the capability to detect them. Infrasound propagation modelling can be used as a forecast tool. As an example, the Alaska Volcano Observatory runs propagation models 24 hours in advance, at 6 hour increments, for volcanic monitoring.

Mohamed ElGabry supported the statements of the other panellists by highlighting the importance of IMS data in regions that lack regional monitoring networks, such as Africa. The use of IMS data for seismic waveform tomography of the Eastern Mediterranean region was also noted.

Öcal Necmioğlu referred to his Invited Talk and provided additional examples related to tsunami warning in the Mediterranean region and the monitoring of earthquakes. The uniqueness of IMS infrasound data, which allowed work on data fusion at the Turkish NDC, was emphasized. In addition, the challenge of the future role of the IMS network, especially if does not further develop while other means expand and diversify, was noted.

In response to a question from the audience, Öcal Necmioğlu emphasized that the CTBTO bulletins should first and foremost serve the verification task. They are not aimed to compete with bulletins from other institutions, such as international seismological centres. To conclude, Mohamed ElGabry called for more cooperation between NDCs in using various data channels for scientific and civil applications.

5.6. J07 – Regional Data for Treaty Monitoring

Moderator: Christos Saragiotis[1]
Panellists: Atalay Ayele[2]; Michelle Grobbelaar[3]; Nortin Peter-David Titus[4]; Robert Mellors[5]; Ronnie Quintero[6]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Institute of Geophysics, Space Science and Astronomy of Addis Ababa University (IGSSA), Ethiopia*
[3]*Council for Geoscience, Pretoria, South Africa*
[4]*Geological Survey, Ministry of Mines and Energy, Namibia*
[5]*University of California, San Diego, CA, USA*
[6]*Observatorio Vulcanologico y Sismologico de Costa Rica (OVSICORI), Costa Rica*
Corresponding Author: christos.saragiotis@ctbto.org
Abstract: *The International Monitoring System (IMS) was designed as a sparse global network with the purpose of detecting nuclear explosions. The sparseness of the network, the complexity of wave propagation in the Earth's interior, the oceans and the atmosphere and the lack of accurate models that describe it limit the accuracy of the location of events detected by the IMS stations. To improve location capabilities the IMS depends on reference events, also known as ground truth events, that is, events the spatiotemporal origin of which is known with high confidence. The characterization of events as ground truth requires the use of dense national and regional networks and cooperation among National Data Centres (NDCs). Furthermore, such cooperation enhances the monitoring capabilities of the NDCs as it allows them to surpass the capabilities of the IMS. This panel will discuss the synergy between the IMS, regional experts and the NDCs and in particular the benefits Treaty monitoring has reaped from regional expert contributions, how the CTBTO contributes to regional needs and how this synergy can be facilitated and further extended in the future.*

Panel J07, moderated by Christos Saragiotis of the PTS, addressed the following questions:

- Ground truth events: What are they and how are they

used to improve regional event location and screening?
- How do regional data contribute to Treaty monitoring?
- How can we achieve better collaboration among neighbouring countries and data sharing for Treaty monitoring?
- What are the challenges for NDCs in sharing data with the CTBTO or other international organizations?
- What are the challenges of data sharing between NDCs?
- What are some examples of the use of regional data for Treaty monitoring?
- What other types of regional data can be used for Treaty monitoring?
- Other questions specific to the panellists.

All panellists underlined the importance of regional networks and ground truth events, not only for Treaty monitoring but also for scientific studies, updating regional velocity models and studying geophysical phenomena. They also emphasized the need for NDC collaboration with the NDCs of neighbouring countries as well as with institutes and organizations within their own countries, as it seems it is often the case that this does not happen. Although there have been many projects that promoted regional collaboration in the past, it sometimes proved difficult to maintain such collaboration. Atalay Ayele emphasized the specific challenges in Africa, including a sparse network and lack of human resources and funding. Nortin Titus discussed the difficulties of operating with a small team and the benefits such teams could gain from cooperation with other centres in the region. Robert Mellors pointed out that regional networks can significantly benefit from the expertise of the IMS in areas such as resilience of power and communication systems.

Key points were made on several specific topics.

All panellists emphasized the importance of sharing data. For instance, it is often the case that using only national stations introduces large azimuthal gaps, and events are not located as accurately as required to be considered ground truth events. Sharing data is often difficult because some institutes or countries see data as a source of income and are not willing to freely share. Also, there is concern with regard to confidentiality and sharing confidential information with neighbouring countries (even on mining events). Data that could be shared are not only waveforms and event bulletins, but also local geology, velocity models and atmospheric models that have been gathered or developed within local projects. It was proposed for the CTBTO to call upon States to share this information on relevant projects. However, it was noted that in order to make data sharing sustainable it needs to be beneficial to all parties.

On ground truth events, Ronnie Quintero noted that the number of ground truth events in the Latin American and the Caribbean region is very small taking into account the seismicity of the Pacific Rim. This is due to lack of collaboration and data sharing among the countries in that region. Michelle Grobbelaar referred to the potential of mining events as ground truth events. Some of these events are very deep, as South Africa has some of the deepest mines in the world. In the past there was very successful collaboration with the CTBTO to develop a database of ground truth events using these mining events.

With regard to capacity building, all panellists noted that although workshops and training organized by the PTS are very useful, the impact fades very quickly. One reason is that staff who receive training often move to other industries that require a similar skill set, such as the mining or oil industries, where the salaries are much higher. However, the main reason is that CTBTO related activities are usually a very small part of their daily activities. Because staff do not practice them often, the momentum gained during station installation or training workshops is not sustained. There were a few suggestions to address this issue:

- More regular training, perhaps every one or two years.

- Creating regional centres to assist the surrounding NDCs and arrange regular training sessions and interaction to maintain momentum. The NDC Forum is a good platform for this. However, sometimes NDC staff do not have the time to visit it, and it usually takes longer to receive answers from the NDC Forum than what is needed when dealing with pressing issues.
- The development of podcasts, videos or online training sessions that are readily available.
- States Signatories could notify and invite PTS staff to participate in monitoring, training or workshops on technologies that may not be directly related to the CTBT but employ some of the technologies used for Treaty verification.

Some other important points were:

- Sustainability is achieved when activities are beneficial to all parties involved.
- Lack of adequate government funding is a big issue in some countries.
- Young people in Africa do not see nuclear weapons as a real threat (South Africa, the only African country to have had a nuclear weapons programme, dismantled the programme approximately 30 years ago). It is important to raise awareness.
- The willingness of Namibia to host more CTBTO workshops, e.g. an infrasound workshop, in the future.

Introductory Talk to Panel J08

Panel J08 was preceded by Introductory Talk I08-723 by Stuart Russell.

5.7. I08-723 – Knowledge Versus Data

Speaker: Stuart Russell[1]
[1]*University of California, Berkeley, CA, USA*
Corresponding Author: russell@cs.berkeley.edu
Abstract: *For most of its history, AI focused on knowledge-based systems – that is, systems that know things and can reason with that knowledge. In the preceding decade, knowledge was replaced by data and reasoning disappeared. Unfortunately, the absence of knowledge means that modern AI systems based on deep learning require vast amounts of training data and generalize very poorly. In contrast, humans know a lot and learn effectively from very few examples. This is not a coincidence. It is entirely possible to combine knowledge and data, reasoning and learning. One technology that does this is probabilistic programming, which combines several important ideas from mathematics including logic, probability, and universal machines. I will illustrate these ideas in the context of CTBT monitoring.*

Introductory Talk I08-723 began with a description of what artificial intelligence is and what it is not. AI is not about conscious machines or the flashy demonstrations we hear about in the news. Machine learning methods improve the performance of AI systems through experience, and they can be applied to almost any kind of system, such as logical knowledge, probability models or neural networks, parametric circuits, C++ programs, etc. It is important to understand how much of a method is 'model based' versus 'model free' or 'black box'. This relates to the extent that the system is based on identifiable 'knowledge'.

In Bayesian model based approaches, the probability model is conceptually divided into two parts: a generative prior on what the world could be like, and a sensor model for how evidence arises. Parameters can be estimated on the basis of historical data. Bayesian methods invert the probability model and derive the probabilities for inferences about the world given the measured signals. Probabilistic programming developed since 1997 provides universally expressive modelling capabilities and general purpose inference and can efficiently represent any computable probability model, perform inference/learning and cumulatively combine prior knowledge and data.

The principles of Bayesian models were applied in developing NET-VISA for analysis and inference from IMS data. The model includes elementary geophysics of natural and anthropogenic seismicity, information on seismic phases, travel times, attenuation, detection probabilities and noise thresholds. The inference from NET-VISA naturally yields multilateration, noise rejection, ranking of competing hypotheses and handling of negative evidence (when a signal is not recorded). As an illustration of the power of the method, the NET-VISA automatic determination of the location of the 2013 announced nuclear test by the Democratic People's Republic of Korea was shown to be much closer to the tunnel entrance than the location published in the Late Event Bulletin of the IDC.

A recent development is the SIG-VISA tool. SIG-VISA considers the full waveforms and adds to the analysis the consideration of general waveform shape and coda decay rate, superposition of signals, spatial continuity of travel time residuals, repeatability of waveforms and more. The performed inference naturally yields sub-threshold detection, global beamforming, locations from single station detections and accurate locations via 'double-differencing'. SIG-VISA can lead to improvements such as better detection sensitivity and location accuracy. For example, applying SIG-VISA to one year of data from the western United States of America yielded more than twice the number of events than the Late Event Bulletin for magnitude mb between 2 and 2.5, and 10 times the number of events for mb between 1 and 2.

Looking forward, human oversight is still important to handle un-modelled phenomena (e.g. meteorite/ocean, other phases); errors in picking, alignment and association; and unusual waveforms. Stuart Russell suggested considering the use of bulletins where multiple hypotheses and probabilities are presented. Models should be re-estimated continuously, rather than remain fixed. The policy of flagging events should be based on realizing the relative costs of false positives and false negatives and basing the determination of thresholds on such analysis. In conclusion, he predicted that AI systems would eventually surpass human abilities.

5.8. J08 – Human Versus Machine

Convener: Ronan Le Bras[1]
Moderator: Heidi Kuzma[2]
Panellists: Dimitri Kusnezov[3]; Kardi Teknomo[4]; Stuart Russell[5]; Tegawendé F. Bissyandé[6]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*LRH Energy Capital LLC, CA, USA*
[3]*Deputy Under Secretary for AI and Technology at the US Department of Energy*
[4]*Petra Christian University, Indonesia*
[5]*University of California, Berkeley, CA, USA*
[6]*University of Luxembourg, Luxembourg*
Abstract: *Big Data, Machine Learning (ML), and Artificial Intelligence are more and more parts of our daily lives with applications such as self-driving cars, multimedia streaming and shopping suggestions, identification of financial crimes, and medical diagnosis. For CTBT, early adoption of ML methods took place in the 1990s with applications ranging from the monitoring of the network, to data processing and analysis, to the way OSI inspections can be conducted. The methods currently in place could probably be boosted by incorporating improved algorithms, for instance with the use of full waveform-based approaches, and by making full use of the twenty years of accumulated data. Progress has been made recently with a Bayesian approach for network processing. Even though overall results of applying ML methods are often impressive, domain experts may formulate*

objections to their use. Reasons may be: (1) Skepticism that an ML algorithm would find a solution if the learning data set does not contain an exact example of the result. Are Bayesian methods a way to dispel these criticisms? (2) Interpretation of the results. How can a particular result be explained to an expert or a client when many ML methods have imbedded decision-making processes which remain opaque to the user?

Panel J08 began with an introduction by Tegawendé Bissyandé and Kardi Teknomo of their work related to machine learning and artificial intelligence. This was followed by a summary of an earlier talk on the subject by Dimitri Kusnezov, which was presented by Heidi Kuzma, who also moderated the panel.

Tegawendé Bissyandé, who specializes in making artificial intelligence results more interpretable to humans, introduced his work on developing software and using AI to check and repair software. Because of the tradeoff between accuracy and interpretability, there are practical reasons to involve analysts when results are marginally probable. Another word for interpretability is 'explainability', and both refer to the ability of a system to present AI results in a way that is readily understood by human analysts.

Kardi Teknomo started his presentation with general questions to analyse what thinking means. Does it mean computing, memorizing, problem solving, cognizing or creating? The challenge in answering the question of whether machines can think is that we are demanding more and more of machines and changing our definition of thinking. When a machine can create music and poems or movies that are comparable to human works, it is a question of whether the machine has reached the level of intelligence of a human. To illustrate this point, the presenter demonstrated some of his own work on artificial music.

Heidi Kuzma summarized the Keynote Address by Dimitri Kusnezov on the opening day of SnT2021. The main thesis was that artificial intelligence can revolutionize the world. It is only nascent at this time and will ultimately make the world more equitable and efficient. AI has already had an impact in science, health and energy. As noted by the previous panellists, AI can correct code, generate music and locate earthquakes. However, it takes a team of humans to build an AI solution. First, one needs to pose the problem, then software engineers design and build a system. As the Internet is now an integral part of many AI systems, people are needed to maintain it and keep it going. Finally, people such as ethicists and decision makers are also required to be part of the teams of these complex systems.

Dimitri Kusnezov explained that AI is more than just a functional implementation of human knowledge. AI is much more interesting than a Wikipedia page or an extensive encyclopedia because it is able to create answers from data in ways that were never thought possible. He shared an example from his recent partnership with the GlaxoSmithKline company to unlock data in drug discovery for the purpose of curing cancer. This was a success story, where data that had previously been considered useless were input into a workflow that included the results of many clinical trials and identified candidates who had a priori good chances of success for participation in further trials.

The panel addressed the following questions:

What is the relative role of humans and machines in selecting solutions and rationalizing the decisions?

All panellists agreed that humans are the final arbiters and that they have the ground truth. Tegawendé Bissyandé said that in some cases there is no need to explain a decision. However, other systems involve human input, as in the example of a trajectory using a mapping application on a mobile device. When machines become more like humans, the role of humans will be to create decisions. When watching a streaming service, humans have the job of rating the movies. They are also the ones to decide if a piece of music generated using AI is beautiful or not. In an AI system, objectives must be specified correctly. For self-driving cars this is difficult, and the current status is that the systems keep making mistakes. In social media, if you try to optimize the engagement to a click-through, the algorithm learns how to be addictive, manipulative or abusive, thus causing social problems that we have to deal with. In the end, we need to learn how to build AI systems with some uncertainty in the objectives.

Stuart Russell expressed concern about autonomous weapons precisely because of their autonomous status, with no human interaction. These weapons are much easier to build and proliferate than nuclear weapons. There is a good reason that nuclear weapons are not widely available, and he has been arguing that autonomous weapons should be under the same restrictions. Dimitri Kusnezov opined that it is a human decision of whether certain types of robots are made available or not. He does not yet see a Pandora's box, where people can no longer control anything.

Currently we solve very specific problems, but can something happen in AI that can change this, where human control is lost? Could AI systems recognize something that was not in the prior or that was not foreseen in the framework of the program?

Tegawendé Bissyandé observed that this cannot happen. The main problem with AI is its use by humans. In his research experience, the easy part is for a machine to self-correct repeatable programming mistakes made by humans. The machine has a harder time running the program because it does not have a notion of what the ground truth is.

Kardi Teknomo noted that unintended features can occur, for instance in artificial music. Stuart Russell reflected on the possibility that NET-VISA would find events that are not like the events found in the catalogue used as the training set. This is handled in NET-VISA by inserting an additional probability to the seismicity prior that an event can happen anywhere. When people sing, they generate continuously modulated noise, and this is difficult to simulate with priors consisting of perfect pitch notes. Reaching an AI behaviour that is close to this takes longer, and more data are needed to train the algorithm. In the early days of AI there was little focus on fundamental principles of reasoning. There was a lot of focus on specific tasks, such as IQ tests or stacking blocks. This is similar to a child learning how to ride a bicycle and then performing the feat of riding without hands. A specific feat is achieved at the price of fragility of the algorithm. The AI algorithm is capable of the fixed objective but of only that. Humans will remain the arbiters until machines lose their fragility. Dimitri Kusnezov maintained that we will find ways to make our life easier whether the machines are less fragile or not.

Is there a possibility of a new 'AI winter'?

Stuart Russell cautioned that we may enter another AI winter, as we did in the 1980s. There is too much hype in some domains, and the expectations of the public are too high compared with what is being delivered. One example is self-driving cars. It has been eight years since the announcement was made that the self-driving car was just around the corner and ready to be placed on the market. In fact, many challenges are still not addressed, and there are major issues in terms of liability. He expects a stampede to the exit on these kinds of technologies.

Kardi Teknomo was more optimistic. There are two extremes. On one hand, there is AI that learns what we feed to it. On the other is AI that can generalize based on what is inside the data itself. The future of AI lies somewhere in between. It is a tool rather than an entity with a personality and will.

Who is responsible for communicating the limitations of AI to the public?

For Dimitri Kusnezov, the question is more who owns the risks, regardless of whether one is working on the electrical grid, in bank loans, or job hiring. There will be different levels of risk depending on the details of the implementation and how AI feeds into the decision making process. The risk of AI is dependent on how you implement it; therefore the implementer owns the risk.

Kardi Teknomo illustrated this by using self-driving cars as an example. Who owns the risk in case of an accident? Who is responsible? Is it the manufacturer, the owner of the car or the government? Stuart Russell maintained that at this point the car manufacturer is responsible, as manufacturers are the only parties that are able to afford the enormous risks. It cannot be the owner of the car, who technically is not driving it and therefore is not in control. Before a self-driving car can be sold to the public to drive anywhere at any time under any condition, major progress must be made. The estimation is that we are at reliability of 99.999 per cent ("5 nines") and we need to be at 99.999999 per cent (reliability of "8 nines"), and that means a lot of ground must be covered until this is reached. It is currently possible for a self-driving car to operate in good weather in the middle of the day, but car owners in the real world need to be able to use their vehicles at any time of day in virtually any weather conditions.

Tegawendé Bissyandé was more optimistic. He said that all of the mistakes that are currently being made are good mistakes, because we learn from them. This is analogous to a toddler learning how to walk, and then trying to run. She will fall at first, but eventually, she will be able to run. Some mistakes are made in implementing the algorithm and other mistakes are built into the algorithm. For instance, for a bank loan algorithm, feeding in priors only for a population from a wealthy area will lead to problems because of the bias it creates when the algorithm is applied to other populations. In this case it is the mistake of the implementer, who applied a perfectly good algorithm to a population for which it was not suited.

Is technological singularity, i.e. AI doing something surprising, interesting and outside of its expectations, achievable?

Kardi Teknomo observed that it is possible that an AI system could do something interesting and surprising, but the system would not be aware of it. Furthermore, a human would have to determine that the conclusion reached by the system was indeed interesting and surprising.

Stuart Russell agreed with this assessment. AI systems have already come up with things outside the box. He explained that the notion of technological singularity is one where a single threshold will be crossed and then the self-improvement will happen at such a fast speed that knowledge will increase and discoveries will happen at a very fast pace, and humans will be left far behind. This is not a new idea, and it was called the "intelligence explosion" by the British mathematician I. J. Good in 1965. There are many dimensions to consider, and there is not a single threshold that will be crossed. The Google search engine, for instance, has a much bigger memory than any single human being. Another example is the AlphaGo program, which is now much better at playing Go than any human being. AI researchers are gradually understanding how to broaden capabilities. You can think of it as many long, narrow corridors that widen as advances are made with AI implementation. For instance, an AI program of the future will be able to not only play Go at a very high, expert level but will also be able to play any kind of two player games and then any kind of multi-player games, and then any kind of multi-player games with partial information. As the corridors get wider, they join up and we then get into very broad generalities. However, AI is still going to be 'dumb' in many ways. As seen in the social media domain, an AI system does not to have to be very capable to cause a lot of

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

damage in the world. AI itself has not changed spectacularly lately, but the ability to implement it has increased significantly with the increase in computer power.

Is it possible that we are exhausting the potential of current techniques of AI and that new ideas need to be explored?

Dimitri Kusnezov sees an increase in complexity. AI is going to capture the complex algorithms at the hardware level. This is similar to what happened with transistors and what is currently happening with convolutional neural networks. We will start building systems blending data and simulations and increasing the complexity through networks of such hardware systems. The outcome from these complex systems will be tremendous and astonishing.

What is your opinion on Alan Turing's statement: "It seems probable that once the machine thinking method has started, it would not take long to outstrip our feeble powers. At some stage therefore we should expect the machines to take control"?

Stuart Russell stated that so far we have built systems with fixed objectives. If we build more and more powerful systems with the wrong fixed objectives, then we have a chess match and create an opponent with objectives that are not aligned with ours. We can end up in a chess match with an adversarial opponent. Therefore we need to get away from building AI systems with fixed objectives.

Tegawendé Bissyandé pointed out that we need to define what is meant by machines taking control. Because machines cannot acquire a will and give themselves objectives, he does not think that machines can take control.

Kardi Teknomo responded that machines have higher capabilities than humans, and given the wrong objectives, in a way, machines can take control. However, the human who built the machine would have set these objectives. The one to take control is not the machine, which is a tool; it is the human who set the wrong objectives.

Heidi Kuzma noted that machines taking control means they have objectives of their own or that perhaps humans erred in setting the objectives.

Dimitri Kusnezov remarked that he could imagine an AI system coming up with an objective, whether unique or not. It is not hard to imagine and is more of an engineering problem. One can imagine injecting something in a critical system that would feed on itself and come up with its own path. However, he does not see the benefit of doing something like this. He agreed with the other panellists that we are far from a world were machines take over and become more like humans.

5.9. Introductory Talks to Panel J09

Panel J09 was preceded by Introductory Talks I07-529 by Philippe Hereil and I09-742 by Loretta Hieber-Girardet.

5.9.1 I07-529 – Use of Infrasound Data for Early Notification of Volcanic Ash Advisory Centres

Speaker: Philippe Hereil[1]
[1] *Meteo France, VAAC Toulouse, France*
Abstract: *Continuous progress has been made in the potential use of infrasound data in support of the International Civil Aviation Organization (ICAO) International Airways Volcano Watch. This work was initiated by a collaboration between CTBTO and the Toulouse Volcanic Ash Advisory Centre (VAAC), resulting in the development of the Volcanic Information System (VIS), under the ARISE (Atmospheric dynamics Research Infra-Structure in Europe) project. VIS provides notifications of possible volcanic*

activity based on infrasound observations by stations in the IMS (International Monitoring System) and other national or research installations. After successful tests using recent eruption data, an alerting bulletin prototype based on VIS has been designed for Toulouse VAAC. Two types of notifications are worthwhile: one in the far field (for early detection of eruptive activity and possible ash emission from poorly instrumented explosive volcanoes); and one in the close field (to enrich the description of the kinetic energy of the eruption and of the volcanic ash release). ICAO and World Meteorological Organization (WMO) encourage the effort to continue with the extension of the proposed approach to other VAACs. This essential step will help in designing new automated products that could contribute to reducing the impact of ash clouds on aviation.

In Introductory Talk I07-529 on the use of infrasound data for early notification of Volcanic Ash Advisory Centres (VAACs), Phillipe Hereil offered a review of historical aviation incidents as a result of ash encounters, and the set-up of the International Airways Volcano Watch (IAVW) in 1987 by the International Civil Aviation Organisation (ICAO) with the support of the WMO. He described the current status of the operation of VAACs and ongoing efforts to improve their capabilities.

VAAC activities are carefully crafted, under ICAO and WMO guidance, with the main objective to issue volcanic ash advisories (VAAs) on a global scale and in near real time. Nine VAACs are sharing these responsibilities globally and operate 24/7, looking for signs of volcanic ash in the atmosphere from a variety of observation networks or pilot reports. Beyond the challenge of detecting volcanic ash on satellite images, predicting ash transport is a complex task for the VAACs, especially while addressing the need of timeliness for the VAA to be relevant.

With that in mind, infrasound technology appears as a useful additional means to collect timely data on eruptions and possibly better characterize the volcanic source. Reaching this status over the last few years is a major step forward for this scientific application of IMS infrasound data, which can now be considered as a possible civil application for disaster risk mitigation.

The volcanic information system (VIS) developed by ARISE (Atmospheric dynamics Research Infra Structure in Europe, H2020 EU project) for VAACs and the use of IMS data and IDC products proved their effectiveness on a range of volcanic eruptions, recently with the eruptions of La Soufrière (St Vincent Island) in April 2021 and Nyiragongo (Democratic Republic of the Congo) in May 2021. For the case of La Soufrière, infrasound signals from station IS25 at Guadeloupe, 300 km away from the volcano, were used to characterize the source term and the eruption chronology. For the Nyiragongo eruption, station IS32 in Kenya, 800 km away, provided valuable data on the eruption kinetics.

Work is planned on improving the ability to calculate the source amplitude from long range infrasound measurements in order to estimate the occurrence, and possibly the height of the ash plume. These are key parameters for ash dispersion models. While analysis methods using infrasound data from the IMS network and multidisciplinary approaches are reaching maturity, work remains to improve the reliability of the VIS and strengthen collaboration between the CTBTO, ICAO and WMO. Integrating data from regional infrasound arrays will further lower response time and improve reliability.

5.9.2 I09-742 – Welcome to Risk: As We Know It, or Do We?

Speaker: Loretta Hieber-Girardet[1]
[1]*United Nations Office for Disaster Risk Mitigation, Geneva, Switzerland*
Abstract: *Risk is systemic, interconnected and cascading. The COVID-19 pandemic has just sent a stark reminder to the world that*

the days of one hazard, one impact are over. A NATECH event like a tsunami leading to a nuclear disaster is just another manifestation of the cascading nature of risk. Climate change is further driving risk across borders, with impacts on all sectors and with longlasting, debilitating socio-economic and environmental consequences. The people hit hardest are those who have done the least to cause these significant changes. It is this complex nature of risk that underpins the Sendai Framework for Disaster Rick Reduction 2015-2030 that marks a paradigmatic shift towards a prevention lens for disaster risk management. UNDRR supports UN Member States in strengthening their risk knowledge, monitoring and capacity development to accelerate risk-informed development pathways and humanitarian action. As Member States move forward with the 2030 Agenda, they need to identify and analyse the broad range of risks they face and put in place appropriate measures to address the systemic nature of risk. 'Business as usual' approach will keep us off-track the development trajectory and we need a transformative change to enhance the resilience of the planet and its people.

To set the stage for the panel on synergy among monitoring systems to address hazard mitigation and global challenges, Loretta Hieber-Girardet of the United Nations Office for Disaster Risk Reduction (UNDRR) gave the presentation I09-742, entitled "Welcome to Risk: As We Know It, or Do We?" She began by presenting the Sendai Framework for Disaster Risk Reduction 2015–2030. The framework applies to the risk of small scale and large sale, frequent and infrequent, sudden and slow-onset disasters caused by natural or anthropogenic hazards, as well as related environmental, technological and biological hazards and risks.

There is a growing understanding that risks must not be compartmentalized and the discussion should not be risk by risk. Climate change is a prime example of the need to take an integrated approach. The COVID-19 pandemic is testing the resilience of many of our systems and has magnified existing inequalities. The key areas of engagement of UNDRR are strengthening risk information and evidence, promoting comprehensive disaster and climate risk management, and scaling up local action to build resilience. In the context of expanding understanding of hazards, the technical report *Hazard Definition and Classification Review* identified 302 hazards, 8 clusters of hazards, and 5 hazards that are nuclear related. These definitions can help countries reform their preparedness in terms of risk reduction. UNDRR helps countries to improve the use of risk information through the Global Risk Assessment Framework (GRAF). GRAF aims to strengthen the capacity of United Nations Member States to generate, disseminate and apply risk information in development and humanitarian contexts in a manner that is reflective of the increasingly systemic, interconnected and cascading nature of risks. The presentation also emphasized the importance of monitoring to measure risks. The majority of the Sendai targets help in deterministic risk analysis based on measuring trends of annual losses faced by the reporting Member States.

5.10. J09 – Synergy Among Monitoring Systems to Address Hazard Mitigation and Global Challenges

Moderator: Bruce Howe[1]
Panellists: Dwikorita Karnawati[2]; Esline Garaebiti[3]; Etienne Charpentier[4]; Steve MacFeely[5]
[1]*University of Hawai'i at Mānoa, HI, USA*
[2]*Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), Jakarta, Indonesia*
[3]*Ministry of Climate Change (MoCC), Vanuatu*
[4]*World Meteorological Organization, Geneva, Switzerland*
[5]*United Nations Conference on Trade and Development (UNCTAD), Geneva, Switzerland*
Abstract: *This panel will discuss existing or potential synergies*

between the CTBT and International Organizations and Agencies to address global challenges, disaster risk prevention and mitigation of natural hazards. From the CTBTO's perspective, these synergies are envisioned in the form of International Monitoring System (IMS) data contribution to institutions that utilize data fusion platforms in order to enhance their mission. Initially, the CTBTO provided data to tsunami warning centres (the CTBTO now has a total of 18 tsunami warning agreements in 17 countries). In recent years the scope of this concept was broadened to include earthquake monitoring, volcano eruption monitoring for aviation and maritime safety, underwater acoustic anomalies monitoring, extreme weather events and phenomena, as well as detection of radioactive emissions and their dispersion to warn and protect citizens. The objectives of such monitoring systems are in-line with global challenges and the goals outlined in the United Nations' Sustainable Development Goals (2030 Development Agenda), the Paris Climate Agreement, and the Sendai Framework on Disaster Risk Reduction. These links will be addressed in the panel.

The goals of panel J09 were to discuss existing or potential synergies between the CTBT and international organizations and agencies in addressing global challenges and to contribute to disaster risk prevention and the mitigation of natural hazards. To begin, Bruce Howe, the moderator of the panel, described the Science Monitoring and Reliable Telecommunications (SMART) project. SMART subsea cables are being developed to integrate environmental sensors into commercial submarine telecommunications cables spanning the global oceans. They will be used to support observations for climate change, ocean circulation, sea level monitoring, the structure of the earth, and tsunami and earthquake early warning and disaster risk reduction. SMART cables will be one of the transformative technologies deployed as part of the 2021–2030 United Nations Decade of Ocean Science for Sustainable Development. SMART observations will contribute to the United Nations Sustainable Development Goals and act in synergy with satellite observations, Argo floats, buoy sensors and IMS stations to address hazard mitigation and global challenges. An example for such a SMART system is CAM-2, which will connect Lisbon, the Azores and Madeira with a ring of 3700 km fibre and is planned to be installed in 2024. SMART cables and IMS stations will complement each other, as the data can be used for CTBT verification purposes and for hazard mitigation and scientific applications.

Dwikorita Karnawati described hazard mitigation efforts in Indonesia, where she is head of the Agency for Meteorology, Climatology and Geophysics (BMKG). Indonesia suffers from a high frequency of earthquakes, volcanos and tsunami events. Indonesia, which has signed and ratified the CTBT, hosts six auxiliary seismic stations. It has also signed a tsunami warning agreement and established the Indonesian Tsunami Early Warning System (InaTEWS). Eight additional auxiliary IMS stations outside Indonesia were also integrated into InaTEWS. The Indonesian NDC plans to add more stations to increase the capability to detect unusual seismic events including volcanic eruptions and tsunami events. Examples of signals recorded from the announced nuclear test by the Democratic People's Republic of Korea in 2017 were shared, as well as signals from the very recent Central Maluku earthquake, which occurred on 16 June 2021, only two weeks before the SnT2021 conference. Submarine volcanoes can be very dangerous, and their monitoring can be very significant in saving lives. Tsunamis typically occur in Indonesia 20 to 30 minutes after earthquakes. However, some tsunamis can occur as quickly as two minutes later, as in 2018. For such cases, the early warning system needs to be improved. Strengthening capacity building in Indonesia was emphasized.

Etienne Charpentier of the WMO discussed how the organization supports disaster risk reduction with regard to high impact weather, floods, heat waves, droughts, climate change, environmental emergency response, tsunami warning and more. WMO looks at the planet as a whole, linking the atmosphere, the ocean and hydrosphere, the terrestrial realm, the cryosphere and the biosphere. The WMO Integrated Global Observing System (WIGOS) consists of diversified means, including satellites, remote sensing, surface stations, ocean buoys and weather ships. Sharing data and filling data gaps is essential, and a new data policy has been established to promote data sharing. The WMO can offer its infrastructure for metadata repository (OSCAR), data exchange (WIS) and provision of information and products (GDPFS). Partners can offer their observing infrastructure to WMO for the installation of ancillary meteorological instruments, especially in regions where data are sparse.

Steve MacFeely, the chief statistician of the United Nations Conference on Trade and Development (UNCTAD) who is about to take a new position at WHO, discussed the 2019 report on the Global Health Security Index, which prophetically warned against the low preparedness level for a possible future pandemic. He noted that the political will for accelerating health security is caught in a perpetual cycle of panic and neglect. The COVID-19 crisis demonstrated the importance of public health systems and public infrastructure. However, knowing the risks is not enough. Political will is needed to take action to save lives and to build a safer and more secure world.

5.11. J10 – Special Talks on the "Anthropocene Epoch", in memory of Paul Crutzen (1933–2021)

5.11.1. I10-749 – Multiple Reasons for the Anthropocene: Paul Crutzen's Contribution to Saving Planetary Boundaries

Speaker: Hartmut Grassl[1]
[1]*Max Planck Institute for Meteorology, Germany*
Abstract: *The present geological epoch is now called "Anthropocene" by most scientists and increasingly by the public, largely stimulated by Paul Crutzen's papers of 2000 and 2006 with this title. This geological epoch is not yet officially accepted, and the exact start time is debated. Whether the Anthropocene started with the steam engine in 1834, Crutzen's proposal in 2006, or the Trinity nuclear test explosion in 1945 as proposed by the Anthropocene Working Group is rather secondary. It is clear that homo sapiens is dominating planet Earth and has already transgressed save planetary boundaries for several element cycles (e.g. carbon, nitrogen). Hence, we have to reverse the trend by global governance. As done successfully with the Montreal Protocol as part of the Vienna Convention to Protect the Ozone Layer, for which Paul Crutzen's Nobel Prize honored research laid the foundation, and as since 2016 tried by the Paris Agreement to the United Nations Framework Convention on Climate Change. We have not only to discuss but to avoid very close tipping points of the climate system, like the complete melting of the Greenland ice sheet. To many of these scientific challenges Paul Crutzen has strongly contributed.*

In Invited Talk I10-749, climate scientist Hartmut Grassl honoured atmospheric chemist and Nobel Prize recipient Paul Crutzen, one of the esteemed scientists who laid the foundation for understanding the transgression of planetary boundaries by humankind through the overuse of natural resources, causing long term global threats. In 1995, the Nobel Prize Committee of the Swedish Academy of Sciences recognized Crutzen as a scientist who took a fundamental step towards a deeper understanding of the chemistry of the ozone layer and awarded him the Nobel Prize in Chemistry. In 1970, Crutzen showed that the nitrogen oxides NO and NO_2 react catalytically (without themselves being consumed) with ozone, thus accelerating the rate of reduction of the ozone content. Hence, the global increase in nitrogen fertilization increases the attack on the stratospheric ozone layer. This understanding has helped to explain the comparably low ozone concentration in the stratosphere under natural conditions that was already observed 15 years before the anthropogenic 'ozone hole' was detected.

It is clear that Homo sapiens is dominating planet earth and has already caused the transgression of planetary boundaries for several element cycles (e.g. carbon, nitrogen). In the International Geosphere–Biosphere Programme (IGBP) Newsletter 38 of May 2000, Crutzen and limnologist Eugene Stoermer introduced the concept of the end of the geological Holocene Epoch and the beginning of what they coined the "Anthropocene" epoch, stating: "Considering these and many other major and still growing impacts of human activities on earth and atmosphere, and at all, including global, scales, it seems to us more than appropriate to emphasize the central role of mankind in geology and ecology by proposing to use the term 'anthropocene' for the current geological epoch."

This term has received worldwide recognition. Even though it is not yet formally established as a geological epoch, the Anthropocene is accepted by most scientists and increasingly by the public. The exact start time is still under debate. Crutzen proposed in 2006 that the Anthropocene started with the steam engine in 1834, whereas the Anthropocene Working Group of the Subcommission on Quaternary Stratigraphy considers the Trinity nuclear test explosion in 1945 as a suitable start date.

Hartmut Grassl argued in his presentation that we must reverse the negative trends through global governance. Most urgently, we must avoid the rapidly approaching tipping points of the climate system, such as the complete melting of the Greenland ice sheet. Paul Crutzen had already indicated the way back to a safe zone. His research laid the foundation for the Montreal Protocol as part of the Vienna Convention for the Protection of the Ozone Layer, which became a success story. Another example is the goal set in the Paris Agreement to the United Nations Framework Convention on Climate Change of 2016 to limit global warming to well below 2 degrees, preferably to 1.5 degrees Celsius, compared with pre-industrial levels.

In the discussion, Hartmut Grassl was asked about what would come after the Anthropocene. He observed that the Anthropocene must be overcome with decisive measures through international cooperation and implemented through international law. If successful, the world would have reached a status that can be described by the German term of *Weltinnenpolitik*, which in English is referred to as global governance. He stressed the importance of moving from a world of conflicts to a paradigm of multilateral cooperation and pointed to the Intergovernmental Panel on Climate Change (IPCC) as an example of how this can be implemented. In fact, the CTBT is another example of fruitful multilateral cooperation, even though 25 years after opening for signature it has yet to enter into force.

5.11.2. I10-752 – Artificial Radionuclide Fallout: A Marker for the Start of the Anthropocene Epoch

Speaker: Colin Waters[1]
[1]*University of Leicester, United Kingdom*
Abstract: *The Anthropocene Working Group of the Subcommission on Quaternary Stratigraphy is tasked with gathering evidence to assess the Anthropocene as a potential new formal unit within the Geological Time Scale. If approved, this would be the first such unit that directly reflects a pervasive shift in the Earth System due to human activities. Evidence includes the appearance and rapid dispersal of many new mineral forms, rock types and modification of sedimentary processes. Biological evidence includes the irreversible consequences of extinctions, unprecedented species invasions and dominance of domesticated species. Recent climate and sea level trends are outside the trajectory of the previous ~11,000 years. Chemical signals include isotope patterns altered by unprecedented perturbations to the carbon and nitrogen cycles, with many disseminated metal and persistent organic pollutants forming novel signatures. Anthropogenic influence on geological signals commenced thousands of years ago, but the mid-20th century provides the most pronounced inflection in most global trends, reflecting surges in human population, energy consumption*

(especially hydrocarbons), technological innovation and international trade. Despite atmospheric testing of nuclear devices not being a fundamental cause of this Earth System shift, these detonations have left almost globally synchronous radionuclides traces ideal for marking the onset of the Anthropocene in multiple geological archives. This presentation details the variable nature and associated problems related to using the so-called "bomb-spike" and ongoing plans for developing a proposal for a formal "golden-spike" section in potential host environments.

Invited Talk I10-752 began with an introduction of the accepted scheme of geological time scales, where officially we are now in the Holocene Epoch, which started at the end of the last ice age, some 11,000 years ago. In terms of the new Anthropocene epoch, which was proposed to mark the growing impact of humankind on the earth, artificial radionuclide fallout is suggested as a marker.

The Anthropocene Working Group of the Subcommission on Quaternary Stratigraphy, which is chaired by presenter Colin Waters, is tasked with gathering evidence to assess the Anthropocene as a potential new formal unit within the geological time scale. The late Nobel Prize winner Paul Crutzen, who popularized the term 'Anthropocene' in 2000, had been a member of the working group until his death on 28 January 2021. The range of proxy signals include new mineral forms and sediments; biological evidence such as extinctions, climate change and sea level trends; and chemical signals including isotope patterns and artificial radionuclide traces.

Evidence includes the appearance and rapid dispersal of more than 200,000 synthetic mineral-like substances compared with roughly 5100 natural minerals. An example is tungsten carbide, which has been included in hundreds of billions of ballpoint pens since 1961. Plastic production has grown very fast and reached a mass of 380 Mt in 2015. Overall, 316 billion tonnes of sediments were produced by humans in 2014 (approximately 43 tonnes per person).

Several previously recognized transitions in geological periods have been marked with mass extinctions. The recent rate of species extinction has accelerated due to human activity, with an estimated 338 vertebrate species becoming extinct over the last 500 years. We may be heading towards what might be called "a sixth mass extinction" in the next 200 years.

Global temperature rise lags other markers, but it has increased consistently since 1975 and is more than two orders of magnitude faster than at the Pleistocene–Holocene transition. We were using about 80 to 90 times more energy in 2010 than in 1800. There has been an unprecedented scale of change in levels of CO_2, CH_4 and N_2O in the atmosphere. CO_2 concentration is the highest for the last 3 million years, CH_4 concentration is at its highest for at least 800,000 years, and reactive nitrogen may be at the highest level of the last 2.5 billion years.

Artificial radionuclide fallout from nuclear explosions provides a global signal, dominated by the fallout from 543 atmospheric weapon tests. This can serve as a sharp and global stratigraphic marker. Suitable markers may be ^{240}Pu and especially ^{239}Pu, with a relatively long lifetime (24,110 year half-life), a sharp rise in 1952 (and peak in 1963), low solubility and high reactivity. A ^{14}C peak is also easily distinguished in tree rings and in cave deposits. The presentation showed examples of plutonium signals in lake and sea sediments, glaciers and corals, which have a clear annual signal. Possible issues with choosing the right marker were also discussed. Some signals show lags between the onset and the peak, and there are differences in the tail behaviour. One needs to avoid areas with proximal nuclear detonations to better measure the global signature. There is a potential effect of plutonium mobility in acidic/anoxic conditions (peats, lakes). Plutonium signals are not seen in speleothems and have low concentrations in Antarctic ice.

In summary, the presentation maintained that there is a basis to claim that the earth system departed from its Holocene state around 1950, forcing abrupt physical, chemical and biological changes to the geological record. Fallout associated with nuclear weapons testing is not a key driver of these changes, but it provides a globally synchronous marker coincident with the onset of the Anthropocene. Plutonium-239 has been suggested to provide the most reliable long term signal, commencing in around 1952. Work is ongoing to formalize the Anthropocene epoch as a geological time unit. This will require selection and approval of a Global Boundary Stratotype Section and Point (GSSP), the 'golden spike' that marks the precise boundary between geological periods.

Panel Discussion on Science Communication

5.12. J11 – Communicating Uncertainty Among Scientists to Policy Makers and the Public

Moderator: Peter Rickwood[1]
Panellists: Angela Me[2]; James Gillies[3]; Nimar Arora[4]; Sayed Mekhaimer[5]
[1]*Atomic Reporters*
[2]*Chief Research and Trend Analysis Branch at the United Nations Office on Drugs and Crime (UNODC, Vienna)*
[3]*Particle Physicist and Senior Communications Advisor at the European Organization for Nuclear Research (CERN) (Geneva, Switzerland), former Head of Communications at CERN*
[4]*Founder of Bayesian Logic Inc., Berkeley, (California, USA)*
[5]*National Data Centre and National Institute of Astronomy and Geophysics (NRIAG), Cairo (Egypt)*

Abstract: *Uncertainty inherently affects every measurement and each scientific statement. This basic fact is often overlooked in communication between scientists, and even more so in the public conversation on scientific topics. Scientific results, be they the product of preliminary investigations or firmer outcomes of peer-reviewed studies, are often perceived as immutable, overlooking the fact that all findings are subject to continuous scrutiny and revision as new data or theories become available. Regional and cultural perspectives also play a role in the communication and perception of uncertainty. Failure to communicate effectively on this issue can undermine public confidence and have a direct impact on perceptions of risk, and the consequences of such misconceptions have become especially prominent in the context of the global coronavirus pandemic. In the CTBT context, uncertainty is an inescapable element of the characterization and communication of Treaty-relevant events, as well as in the framework of civil and scientific applications. This panel discussion addresses strategies for effectively communicating uncertainty when reporting about science, with the objective of delivering a clear message to audiences. It is relevant for scientists, policy makers and public information professionals.*

Panel J11 was moderated by journalist Peter Rickwood, who has considerable experience in science communication and nuclear matters. The panellists included a statistics expert at the United Nations Office on Drugs and Crime (UNODC) who deals with communicating complex statistical findings and uncertainty to policymakers, media and the public; a science communication expert from the European Organization for Nuclear Research (CERN); and two scientists who deal with incorporating uncertainty in IDC processing (NET-VISA for waveform processing and uncertainty in ATM for radionuclide processing).

The discussions highlighted how uncertainty is often overlooked in communication between scientists, and even more so in the public conversation on scientific topics. It also highlighted how the media tend to avoid taking uncertainty into account in their reporting, and how policymakers themselves tend to reject statements that acknowledge uncertainty. The panellists and moderator all provided examples from their own experience. Angela Me recounted that it is often the case that when information stating ranges of uncertainty is distributed to media and policymakers, only the midpoint of the range is discussed, while the range of uncertainty is ignored for the sake of simplicity. This, however, leads to a discussion that neglects the uncertainty that is intrinsic to the data. Such uncertainties are sometimes essential for decision making, and this can mask finer details that the scientists are aware of.

Nimar Arora described probabilistic programming approaches that enable the computation of probabilities taking into account the beliefs and the assumptions of the scientist who analyses the data. All inference involves beliefs and assumptions, and Bayesian methods are based on explicitly recognizing and stating such beliefs. He maintained that the public is ready to accept such presentation of probabilities and noted that Bayesian methods have been at the heart of his work for the CTBTO.

Angela Me agreed, but pointed out that the public needs to be trained and educated to think in statistical terms. There are people who are better skilled in communication, and these are not necessarily the scientists who are responsible for the research.

Sayed Mekhaimer reflected on the various sources of scientific uncertainties, not only in measurements, but also in models. Atmospheric sciences deal with nonlinear systems that are sensitive to slight changes in initial conditions. Although people find it hard to take decisions with a forecast that gives a 45 per cent chance of rain, uncertainties still must be communicated.

James Gillies noted that funding issues are important, and there is a need to correctly inform decision makers about the prospects and risks of new scientific endeavours that they fund. The correct attitude is not in claiming certainty, but in presenting data in such a way that allows informed decisions. An example was provided from CERN, which needed to respond to improbable claims that its projects could produce black holes that endanger the existence of the earth. This was accomplished by presenting evidence that such a risk cannot be considered as likely enough to cause any concern. The importance of social media as a means to inform the public about how science is done and create a dialogue about it was emphasized.

The consensus of the discussion was that uncertainty needs to become part of the global discourse on science and technology at all levels (and on CTBT monitoring and Treaty implementation in particular). Global issues such as the dangers of global warming and the questions of COVID-19 vaccinations need to be communicated to the public and policymakers in a way that correctly conveys the uncertainties and enables the decisions required to mitigate the dangers. This requires clear communication, and to a certain extent 'education' of the public and the media, to acknowledge the significance and non-trivial role of uncertainty and promote greater understanding of the need to include and understand uncertainty in any scientific and technical discussion, be it among specialists, stakeholders or the public.

5.13. SE5 – Session on National Data Centres

Convener: Gérard Rambolamanana[1]
Q&A Moderator: Alexander Poplavskiy[1]
Speakers: Gonzalo Antonio Fernandez Gustavo Gonzalez[2]; Andry Harifidy Ramanantsoa[3]; Daniela Ghica[4]; Alexandr Smirnoff[5]; J. Ole Ross[6]

[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Observatorio San Calixto, La Paz, Bolivia*
[3]*Institute and Observatory of Geophysics of Antananarivo (IOGA), Madagascar*
[4]*National Institute for Earth Physics (NIEP), Bucarest, Romania*
[5]*Institute of Geophysical Research, Almaty, Kazakhstan*
[6]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*

Abstract: *NDCs (National Data Centres) are the national technical organizations competent to advise their governments on the verification of the Comprehensive Nuclear-Test-Ban*

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Treaty. The objective of this session was to allow NDC experts to share experience in fulfilling their verification responsibilities. Presentations and discussions emphasized use of IMS data and IDC products for verification purposes as well as civil or scientific applications, use of NDC in a box or specific tools in operation at NDCs, and collaboration and interaction between NDCs.

The NDC Session (SE5) was convened by Gérard Rambolamanana and moderated by Alexander Poplavskiy, both of the PTS.

Gonzalo Antonio Fernandez, Director of the Observatorio San Calixto (OSC), Bolivia, discussed the transition of the NDC from an isolated seismic–infrasound acquisition system to a research and development system. OSC is a Jesuit, nonprofit private research institution that was established in 1913. It is in charge of seismic and infrasound monitoring at both local and regional level, as well as seismic hazard studies in Bolivia. OSC has scientific agreements with the Commissariat à l'energie atomique et aux énergies alternatives, France (CEA) and the Air Force Technical Application Center, United States of America (AFTAC). With the support of these institutions, the authorities in Bolivia certified primary seismic station PS6, auxiliary seismic station AS8 and infrasound array IS8. Since then, a set of three different acquisition software applications has been implemented at the NDC. It was complicated to merge the earthquake localization solutions. However, since 2016 the NDC has benefited from a capacity building system that comprises a server, workstations and a backup system. The NDC now receives all data from the certified stations and some data from the open seismic network in neighbouring countries. As a result, the NDC is performing efficient monitoring and conducting new studies.

Andry Harifidy Ramanantsoa, Researcher at the Seismology and Infrasound Laboratory, Institute and Observatory of Geophysics of Antananarivo, presented the history of the Madagascar NDC, a summary of its activities during 20 years of operation and the main achievements of the NDC since its establishment. The Madagascar NDC began operating at the end of 2001, after the installation of infrasound and seismic stations. Data are processed using NDC in a box software applications. Rigorous maintenance of the system has resulted in data availability of 99 per cent. Training of NDC staff in system maintenance and data processing has made this possible. Participation in the CTBT: Science and Technology conference series and Infrasound Technology Workshops have provided opportunities for the NDC to present research results to the community.

Daniela Ghica, Head of the National Institute for Earth Physics in Romania, provided an overview of infrasound processing at the Romanian NDC. Beginning in 2009, three infrasound stations were deployed in Romania by the National Institute for Earth Physics (NIEP): IPLOR (in central Romania); BURARI (in northern Romania), in cooperation with AFTAC; and temporary PTS portable array I67RO (in western Romania). The temporary array was deployed as two year experiment (2016–2018) in collaboration with the CTBTO. The infrasound data processing capabilities of NDC in a box have been used since 2016, when the infrasound detection oriented software DTK-GPMCC and DTK-DIVA were integrated into the system. Recorded data are automatically processed by DTK-PMCC. DTK-GPMCC is applied to study the detected signals in detail, including the capacity of fusing them into approximate source location by cross-bearing. DTK-DIVA is used to investigate the performance of the array, i.e. detection capability, types of sources observed, ambient noise conditions, etc. In addition to the data recorded by local stations, the Romanian NDC processes data from the IMS infrasound network in order to jointly characterize large events (bolides, explosions). Furthermore, IDC products such as Late Event Bulletins proved to be very useful to identify the detections observed by the Romanian infrasound stations.

The Romanian NDC also benefited from technical assistance provided by the PTS, including the NDC in a box SHI software package, infrasound data analysis training (intermediate level in July 2019 and advanced level in October 2019), as well as valuable guidance from PTS staff.

Alexandr Smirnov, Deputy Director of the NDC in Kazakhstan, presented the activities of the NDC in support of the CTBTO. The NDC conducts monitoring around the clock. All data from the stations are collected and processed for use in seismic and infrasound bulletins and databases. Annually, seismic bulletins include around 20,000 events, comprising both earthquakes and explosions. This information is used in the interest of Kazakhstan to estimate seismic hazards, to monitor technogenic seismicity in mineral production fields, to ensure the safety of facilities and to study potential locations of future facilities. For many years, the NDC has worked on saving the historical records of nuclear explosions, which is of paramount importance for scientific research. The NDC also continuously cooperates with international and national seismological centres.

Ole Ross, Specialist for ATM and multi-technology analysis at the Federal Institute for Geosciences and Natural Resources in Germany, discussed the NDC Preparedness Exercise (NPE) in 2019, including lessons learned, the application of results from the 2019 NPE and the outlook for future NPEs. He has been engaged in the organization and creation of NPE scenarios since 2012.

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

6 Oral and Poster Presentations

6. Oral and Poster Presentations

6.1. Theme 1: The Earth as a Complex System

This theme focuses on the dynamic or static properties and processes of the earth whose characterization is necessary for the optimum processing, interpretation and assessment of monitoring data. Scientific and technical advances in monitoring the globe for nuclear explosions require an understanding of the way in which features of the earth influence relevant signals as they travel from their point of origin to points where signals are observed. The signals from monitoring networks, as well as noise recorded by those networks, constitute a massive reservoir of data that can support advances in the earth sciences on a local, regional and global scale. Elements of the monitoring effort also need to be able to consider the complexities of the earth as a social system, specifically the interference between anthropogenic aspects and the earth's system processes, as they are connected and may interact with each other. One focus continues to be seismic and acoustic wave speed and attenuation, which are essential for locating seismoacoustic disturbances in the earth and its atmosphere and oceans. Another area is atmospheric dynamics relevant to the transport of radionuclides and the propagation of atmospheric infrasound. Subsurface properties relevant to the detection of a nuclear explosion by geophysical, radionuclide or other methods during an OSI constitute another area of interest. In addition to current monitoring technologies in all of these domains, novel methods of monitoring that could potentially be used by NDCs might require characterization and understanding of specific properties of the earth's subsystems.

T1.1 The Atmosphere and Its Dynamics

Highlights

Infrasound Event Catalogues, Noise and Interpretation

Comprehensive reprocessing of the IMS infrasound database was presented in O1.1-389 and P1.1-399. The presentations covered the period from January 2003 to December 2020, with data from up to 53 stations. The catalogue of coherent signals obtained using the PMCC array processing algorithm permits more accurate signal and source discrimination. The presentation focused on the relation of coherent ambient infrasound to middle atmosphere dynamics. The data products consist of mountain-associated wave events (0.01–0.05 Hz), a low frequency (0.1–0.3 Hz) and a high frequency (0.4–0.6 Hz) microbarom data set, and observations with centre frequencies of approximately 1–2 Hz, including signals from large fireballs and volcanic eruptions that provide information relevant to civil security.

Noise events in the atmosphere, or "perturbators", can cause false detection of events. Probabilistic inference methods are often based on priors that are poorly constrained, and on extremely simplified propagation models. P1.1-627 introduced a new hybrid framework to derive prior probability models from waveform modelling and take advantage of events accumulated in the REB. Unsupervised machine learning can be used to extract information from IMS data that can be translated into better constraining automated tasks at the IDC.

Ground truth data analysis is necessary for infrasound model validation. Using software developed to consistently analyse a global ground truth database, P1.1-158 constructed empirical models for celerity, back azimuth and duration from 312 detections in the 0.32–1.28 Hz passband. The probability distribution for back azimuth is consistent with the NET-VISA

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

back azimuth prior derived using seismoacoustic events. The results do not support a model with increase in stratospheric signal celerity at a distance of 20°, and work is perceived to provide a range-dependent model whose uncertainties reflect the lack of observations at these longer ranges.

Infrasound radiated during periods of weather changes is an almost continuous background against which infrasound monitoring of explosions in the atmosphere is carried out. P1.1-547 discussed the use of microbarometer arrays for verification and civil applications such as forecasting extreme weather events. It demonstrated the forecasting potential by studying two recent extreme weather events in the Netherlands. Data from a dense observational network of light detection and ranging (lidar) facilities and a microbarometer array network were found to agree well with forecasts from global and regional weather forecast models. P1.1-126 described the temporal variation of the infrasound signals detected during a passage of warm and cold fronts through the networks of microbarometers in the cities of Dubna and Moscow in the Russian Federation.

Microbarom Signals

Microbarom signals are generated by wind waves at the ocean surface and propagate all around the globe through the stratosphere and ionosphere. They dominate the coherent infrasound ambient noise measured anywhere on earth, with a peak at around 0.2 Hz. O1.1-531 discussed how this ubiquitous signal can be used to study the properties of the middle atmosphere. A first quantitative validation of global microbarom modelling was done using a new source model, an ocean wave model and atmospheric attenuation parameterization. P1.1-306 compared infrasound data recorded at station IS37 (Norway) in 2014–2019 with simulated microbarom soundscapes. The research used vespagram images that show the signal power dependence on time and direction. Calculations were performed for several frequency bands within the 0.1–0.6 Hz range. The results revealed good agreement between model and data and demonstrated the ability of vespagrams to monitor the microbarom parameters on a seasonal scale, as well as changes during sudden stratospheric warming. P1.1-522 made a comparison between simulations and infrasound recordings in the microbarom band obtained by the Infrasound-Logger, a miniature sensor that was deployed near the Crozet Islands in January 2020. A good agreement was achieved, with the reconstructed soundscape being within ±5 dB for 80 per cent of the measurements in the frequency band of 0.1–0.3 Hz.

Models and Validation Experiments

Current generation numerical weather prediction models are excellent tools for simulating mesoscale meteorology. However, it is very challenging to run models at microscale resolutions over complex terrain, as discussed in O1.1-596. A sequence of field experiments in 2019 at the Lawrence Livermore National Laboratory Site 300 included the controlled generation, observation and monitoring of plumes in a region of complex terrain. Data from these field experiments were used to evaluate model performance and inform model development.

Both forward and backward approaches can be applied for inverse modelling to investigate unknown sources of atmospheric pollutant emission. P1.1-650 used the Cross-Appalachian Tracer Experiment (CAPTEX) field experiment as a test case to compute the source–receptor sensitivity between the known sources and air samples collected at 84 measurement sites. The differences between the forward and backward sensitivities calculated using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model were discussed in the presentation.

Small scale atmospheric perturbations known as gravity waves are critical to infrasound propagation simulations, as they alter the propagation path of the waves, causing detections at infrasound stations that remain unexplained when only large scale atmospheric features are considered. P1.1-491 explored how differences in infrasound-related parameters derived from a ray tracing tool relate to differences in the resolved tropospheric and stratospheric wind and temperature fields. Some models could resolve gravity waves up to the stratosphere. Lidar observations are used to assess the modelled fields and to bring ground truth atmospheric specification for infrasound propagation simulations.

P1.1-215 presented InfraPy, InfraGA/GeoAc and stochprop, open-source software tools for infrasound signal analysis and propagation modelling developed at Los Alamos National Laboratory. P1.1-147 presented the Infrasound Event Analyzer graphic user interface that is under development by the NDC of Tunisia, in which NDC in a box software tools are easily available.

Local and Regional Observations

O1.1-320 presented the first local bulletin from data from IS8 (Bolivia), dating from 2014 to 2020. It includes a wide variety of infrasound sources, observed during different seasons, such as microbaroms, volcanic explosions, earthquakes (M >7) and meteors. P1.1-626 focused on defining and characterizing mines and quarries as the most important coherent infrasonic noise at IS48 (Tunisia). P1.1-464 examined the detectability of signals from Norwegian artillery exercises. At up to 70 km distance, signals are generally observed when stronger, lower tropospheric winds (1–5 km altitude) blow in the direction of propagation. When crosswinds dominate the wind field, low amplitude infrasound arrivals are still observed in the acoustic shadow zone while not predicted by ray tracing simulations, highlighting the model and propagation uncertainties introduced by small scale wind heterogeneities and diffraction effects. Similarly, strong dependence on season and atmospheric conditions was reported in P1.1-251. This presentation looked at the signal detectability of engine tests of the European Ariane 5 rocket at IS26 (Germany) within a range of about 320 km. Models showed significant seasonal variability in the sound speed profiles, but in nearly a quarter of the cases of non-detections they still showed sound speed profiles that should have enabled the observation of infrasound signals.

P1.1-458 discussed signals from supersonic aircraft activity that are detected routinely at the infrasound stations in Romania. These signals are observed from short ranges (140 km) to long distances (2200 km).

P1.1-416 evaluated a statistical model of seasonal rainfall forecasts in Cameroon. P1.1-064 (European Union Star Award winner) looked at the impact of Nyepi, a day of complete rest, on weather parameters in Bali, Indonesia.

Beirut Port Explosion

The accidental explosion at the Beirut port on 4 August 2020 produced strong and unusual infrasound signals that were picked up by five IMS infrasound stations located from 2400 km (IS48 Tunisia) to 6200 km (IS11, Cabo Verde) and several national infrasound stations. This event was discussed in P1.1-401, which was chosen as the best e-poster presentation, as well as in P1.1-137, P1.1-588 and P1.1-672. The ground truth and multi-phenomenon observations allow assessment of the challenges for source localization accuracy and energy estimation. The location was determined by the distant IMS infrasound observations with an error of about 45 km and a yield estimate of approximately 0.5 kt TNT equivalent. The location error can be further reduced to 2 km if one seismic signal is added to the infrasound signals. The data suggest that the propagation conditions at the time of the accident were more complex than a single stratospheric duct, which is typical for mid-summer conditions in the Northern Hemisphere.

Volcanic Eruptions

Many volcanoes worldwide are poorly monitored. Explosive eruptions produce infrasound that is detected at thousands of kilometres. The use of dense seismoacoustic networks could provide timely and reliable information on these eruptions to Volcanic Ash Advisory Centers. Large explosive volcanic eruptions such as those of the Stromboli (Italy), Raikoke (Russian Federation) and Ulawun (Papua New Guinea) volcanoes occurred over the last two years, as described in P1.1-133, P1.1-588 and O1.1-457 (other recent eruptions were addressed in other topic presentations, for example Anak Krakatau in P2.3-708 and Taal in P5.2-395). In-depth analysis and multidisciplinary investigation help to advance monitoring capabilities, to better characterize the sources, to better forecast impacts and to evaluate state of the art observation and simulation methods. Research progress demonstrates the important role of the IMS network and how it can be enriched by well-designed and optimized regional networks (P1.1-264) in order to notify civil society and mitigate volcanic hazards (O1.1-536 and P1.1-133). The accurate extraction of source parameters from infrasound recordings and other observation techniques further advances the quality of mitigation measures. The potential of multidisciplinary approaches also proves to be critical (I07-529) to remotely characterize volcanic eruptions rapidly and accurately (O1.1-457, P1.1-253).

O1.1 The Atmosphere and Its Dynamics Abstracts of Oral Presentations

O1.1-320 – Obtaining the Infrasound Bulletin for IS8

Authors: Gonzalo Antonio Fernandez[1]; Bastien Joly[2]
Co-authors: Mayra Nieto Canaviri[1]; Jonas Baldivieso[1]; Felipe Condori[1]; Stephanie Godey[2]; Julien Vergoz[2]; Nicolas Brachet[2]; Ruben Tintaya[1]
[1]*Observatorio San Calixto, La Paz, Bolivia*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: director@osc.org.bo

The IS08 infrasound array in Bolivia contributes to the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty Organization since 1999. Real time data, which are received at the Bolivian National Data Center (Observatorio San Calixto, OSC) through a VSAT link, are used on a daily basis for scientific and civil applications. Installed in the Central Andes, IS08 has provided valuable high quality data to the CTBTO community. In 2019, staff from the Bolivian NDC attended a basic training in Costa Rica that provided complementary knowledge in infrasound data processing. Since then, thanks to the support of the French NDC and CTBTO, the OSC staff has achieved a major step by setting up the operational chain of processing for real-time infrasound data acquisition, detection and analysis. DTK-GPMCC and DTK-DIVA are used to produce local and regional infrasound bulletins. We are now able to present our first local IS08 bulletin from 2014 to 2020, which includes a wide variety of infrasound sources observed at different seasons such as microbaroms, volcanic explosions, earthquakes (M>7) and meteors. Further improvements to our daily routine analysis to enhance our local bulletin will include the comparison with Late Event Bulletin (LEB) from CTBTO.
Promotional text: Understanding the local infrasound sources is a challenging task, however we decided to start with local characterization of the most frequently sources observed at IS08 (microbaroms, earthquakes, volcano explosions).

O1.1-389 – The Coherent Infrasound Wavefield: New IMS Broadband Bulletin Products for Atmospheric Studies and Civilian Applications

Authors: Patrick Hupe[1]; Lars Ceranna[1]; Alexis Le Pichon[2]; Robin Matoza[3]; Pierrick Mialle[4]
[1]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[3]*University of California, Santa Barbara, CA, USA*
[4]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: patrick.hupe@bgr.de

Our latest comprehensive reprocessing of the IMS infrasound database covers the period from January 2003 to December 2020, representing up to 53 stations considered. The resulting catalogue of coherent signals obtained using the Progressive Multi-Channel Correlation (PMCC) array processing algorithm with a one-third octave frequency band configuration permits more accurate signal and source discrimination. Here we focus on the relation of coherent ambient infrasound to middle atmosphere dynamics and present advanced bulletin products tailored to frequency bands of specific interest by relevant user groups. These bulletin data products consist of mountain-associated wave events (0.01-0.05 Hz), a low-frequency (0.1-0.3 Hz) and a high-frequency (0.4-0.6 Hz) microbarom dataset, and observations with centre frequencies of around 1 to 2 Hz. The latter include, for instance, large fireballs and volcanic eruptions and thus provide information relevant to dedicated applications for civil security. We present selected aspects of these data products and highlight potential applications for atmospheric studies. **Promotional text**: This study builds upon the new global dataset of reprocessed IMS infrasound data (SnT poster by Hupe et al.). Here, we highlight applications and present tailored products being appropriate and useful for atmospheric studies and civil security.

O1.1-45 7 – Multidisciplinary Characterization of the June 2019 Eruptions of Raikoke (Kuril Islands) and Ulawun (Papua New Guinea) Volcanoes Using Remote Technologies

Author: Kathleen McKee[1]
Co-authors: Cassandra Smith[2]; Kevin Reath[3]; Eveanjelene Snee[4]; Sean Maher[5]; Robin Matoza[5]; Simon Carn[6]; Larry Mastin[7]; Kyle Anderson[7]; David Damby[7]; Diana Roman[1]; Artem Degterev[8]; Alexander Rybin[8]; Marina Chibisova[8]; Ima Itikarai[9]; Kila Mulina[9]; Steve Saunders[9]; Jelle Assink[10]; Rodrigo De Negri[5]; Anna Perttu[11]
[1]*Carnegie Institution for Science, Washington, DC, USA*
[2]*Alaska Volcano Observatory, Anchorage, AK, USA*
[3]*Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, NY, USA*
[4]*Cardiff University, United Kingdom*
[5]*University of California, Santa Barbara, CA, USA*
[6]*Michigan Technological University, Houghton, MI, USA*
[7]*U.S. Geological Survey, USA*
[8]*Sakhalin Volcanic Eruptions Response Team (SVERT), Institute of Marine Geology and Geophysics, Yuzhno-Sakhalinsk, Russian Federation*
[9]*Geological Survey of Papua New Guinea, Rabaul, Papua New Guinea*
[10]*Royal Netherlands Meteorological Institute (KNMI), De Bilt, the Netherlands*
[11]*Nanyang Technological University, Earth Observatory of Singapore, Singapore*
Corresponding Author: kfmckee@carnegiescience.edu

Retrospective eruption characterization is valuable for advancing our understanding of volcanic systems and evaluating our observational capabilities, especially with remote technologies (defined here as a space-borne system or non-local, ground-based instrumentation which include regional [15-250 km range] and remote [>250 km range] infrasound sensors). Two of the largest explosive volcanic eruptions of the past decade occurred in June 2019 at Raikoke, Kuril Islands and Ulawun,

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Papua New Guinea volcanoes. We integrated data from the International Monitoring System infrasound network, satellites (including Sentinel-2, TROPOMI, MODIS, Himawari-8), and globally detected lightning (GLD360) with information from local authorities and social media to improve understanding of the eruptive behavior of these volcanoes. Remote infrasound data provide insight into changes in eruption intensity. During both eruptions, the infrasound peak frequency decreases upon transition to the Plinian phase. This may be related to changes in erupted jet and plume dynamics, such as an increase in vent diameter (observed in satellite). Our analysis illustrates the value of interdisciplinary analysis of remote data to illuminate eruptive processes.
Promotional text: Remote (non-local) infrasound data provide critical information in multidisciplinary characterization of two large volcanic eruptions in June 2019.

O1.1-531– Global Microbarom Patterns: Infrasound Ambient Noise Modelling Versus IMS Observation Database

Author: Marine De Carlo[1]
Co-authors: Alexis Le Pichon[2]; Patrick Hupe[3]; Lars Ceranna[3]; Fabrice Ardhuin[4]
[1]*Centre National de la Recherche Scientifique (CNRS), France*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[3]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
[4]*Institut Français de Recherche pour l'Exploitation de la Mer, France*
Corresponding Author: marine.decarlo@gmail.com

Microbarom signals are generated by wind-waves at the ocean surface and propagate all around the globe through the stratosphere and ionosphere. Microbaroms dominate the coherent infrasound ambient noise measured anywhere on Earth, with a particular peak for periods around 5 s. This ubiquitous signal can be used to monitor the medium in which it propagates, allowing to probe the properties of the middle atmosphere. Here we show the first quantitative validation of global microbarom modelling using a new source model, an ocean wave model, and atmospheric attenuation parameterization. The modelling results are compared to a reference database of microbaroms detected by the global infrasound International Monitoring System over seven years to evaluate the influence of ocean waves, source and propagation parameters. This study demonstrates that the new source model performs better than previous models, and is best when this model is combined with a wind dependent attenuation and an ocean wave model that includes coastal reflection. Better knowledge of ambient ocean noise sources opens new perspectives to enhance the characterization of explosive atmospheric events, and provides additional integrated constraints on middle atmosphere dynamics.
Promotional text: This study main outcome is a first global and quantitative validation of a new microbarom source model. New perspectives arise from coupling this source model with refined propagation models in order to enhance coherent noise characterization and assess middle atmospheric models.

O1.1-536 – Reflection on the Importance of IMS-Like Infrasound Stations in Volcanologically Active Areas

Author: Benoit Taisne[1]
Co-authors: Anna Perttu[1]; Dorianne Tailpied[1]; David Whilldin[1]; Siow Kay Wong[1]; Sundod Chulalak[1]
[1]*Nanyang Technological University, Earth Observatory of Singapore, Singapore*
Corresponding Author: btaisne@ntu.edu.sg

With global increases in population and air traffic, our ability to forecast when and where a hazard will occur is of prime importance. In the case of volcanic eruptions, forecasting is not limited to when and where an eruption will take place, but also when and where the impact of such an eruption will be felt. Cross-boundary volcanic ash from explosive volcanic

eruptions is hazardous. The dispersal of volcanic ash could be modeled, however the level of uncertainty drastically depends on our knowledge of the eruption itself. Critical parameters are the duration of the eruption as well as the height of the associated eruptive column. With those 2 parameters you can simulate a range of plausible ash dispersal scenarios. Such parameters could be retrieved by monitoring, research sensors or an array deployed on the flank of the volcanoes. However, in a region with hundreds of active or potentially active volcanoes this is not always possible. We would like to demonstrate a few recent examples for which the IMS and IMS-like (installed in Singapore) infrasound stations were used to extract eruption source parameters.
Promotional text: This presentation aims to demonstrate how useful IMS and IMS-like infrasound stations are in mitigating volcanic impact.

O1.1-596 – Modelling Atmospheric Transport and Dispersion Over Complex Terrain

Author: David Wiersema[1]
Co-authors: Lee Glascoe[1]; Akshay Gowardhan[1]; Katherine Lundquist[1]; Sonia Wharton[1]
[1]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: wiersema1@llnl.gov

The accurate simulation of atmospheric transport and dispersion requires a numerical weather prediction model that is able to resolve both mesoscale meteorology, such as a storm front or sea breeze, and microscale meteorology near the plume source, which is strongly influenced by the presence of complex terrain (i.e., mountains or dense urban development). Current generation numerical weather prediction models are excellent tools for simulating mesoscale meteorology; however, model design constraints present challenges to running at microscale resolutions over complex terrain. These challenges include, but are not limited to, overcoming model restrictions on resolved terrain slopes, parameterizing the effects of turbulent mixing, and appropriately downscaling information from the mesoscale to the microscale. A sequence of field experiments in 2019 at the Lawrence Livermore National Laboratory Site 300 included the controlled generation, observation and monitoring of plumes in a region of complex terrain. Data from these field experiments are used to evaluate model performance and inform model development that will improve the accuracy of transport and dispersion simulations over complex terrain.
Promotional text: This research focuses on understanding and improving the accuracy of atmospheric models used for simulating transport and dispersion over complex terrain.

P1.1 The Atmosphere and Its Dynamics Abstracts of Poster Presentations

P1.1-064 – Nyepi Day Impact on Weather Parameters Measurement at Synoptic Observation Stations in Bali

Author: I Putu Dedy Pratama[1]
Co-authors: Pande Komang Gede Negara[1]; Putu Eka Tulistiawan[1]; I Ketut Sudiarta[1]
[1]*Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), Jakarta, Indonesia*
Corresponding Author: checkmate_mail@yahoo.co.id

Nyepi is a rare activity in the world that only exists in Bali, where all of human outdoor activities stop for a day. This study used Nyepi to measure its impact on changes in weather parameters measurement in Bali. The purpose of this study is to see the effect of Nyepi on the ratio of daily average temperature to duration of solar radiation as well as daily average air humidity at four synoptic stations in Bali. The data that we used are daily average air temperature, duration of solar radiation, and average air humidity from 1999-2020 on Nyepi. As a comparison, we used data from 2 days before and after Nyepi. Based on 22 years of data at the four location points, we obtained that the air temperature in the 5-day range fluctuates and shows a trend of decreasing daily average temperature during Nyepi for all stations. As for the daily average air humidity, the effect of Nyepi is only visible at the Ngurah Rai Meteorological Station as an increase. The average temperature to sunshine ratio during Nyepi, 2 days before and after Nyepi showed that the lowest ratio occurs at Denpasar Geophysical Station and Jembrana Climatology Station.

Promotional text: Nyepi Day, a day for rest the world and refresh the air quality.

P1.1-126 – Infrasound from Meteorological Fronts and Its Possible Generation Mechanism

Author: Igor Chunchuzov[1]
[1]*Obukhov Institute of Atmospheric Physics, Moscow, Russian Federation*
Corresponding Author: igor.chunchuzov@gmail.com

Infrasound radiated during periods of weather changes is an almost continuous background against which infrasound monitoring of explosions in the atmosphere is carried out. In this work the results of study of temporal variations of the characteristics of infrasound (amplitudes, coherences, grazing angles, azimuths and horizontal phase speeds) detected during a passage of warm and cold fronts through the networks of microbarometers in the cities Dubna and Moscow are presented. The significant differences observed in the characteristics of infrasound from warm and cold fronts are discussed. Such differences must be taken into account when detecting infrasound precursors of atmospheric storms. A possible aerodynamic mechanism for the generation of infrasound caused by the turbulent air flow around the geometric irregularities of the surface of meteorological front is proposed. This work was supported by RFBR grants 18-05-00576, 19-05-01008.

P1.1-133 – On the Use of Dense Seismoacoustic Network to Provide Timely Early Warning of Volcanic Eruptions

Authors: Alexis Le Pichon[1]; Christoph Pilger[2]; Lars Ceranna[2]; Viviane Souty[1]; Gilles Mazet-Roux[1]; Julien Vergoz[1]; Bruno Hernandez[1]; Constantino Listowski[1]; Emanuele Marchetti[3]; Philippe Hereil[4]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[2]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
[3]*University of Firenze, Department of Earth Sciences, Firenze, Italy*
[4]*Meteo-France, Toulouse, France*
Corresponding Author: alexis.le-pichon@cea.fr

The Stromboli volcano is known for its persistent explosive activity, with hundreds of explosions every day ejecting ash and scoria up to heights of several hundreds of meters. Such a mild activity is however punctuated by lava flows and major explosions that represent a much larger hazard. On July 3 and August 28 2019, two paroxysmal explosions occurred at Stromboli, generating an eruptive column that quickly rose up to 5 km. Due to an absence of notification of the eruption, the Toulouse Volcanic Ash Advisory Center (VAAC) emitted an advisory to the civil aviation with a two-hour delay. The various processes of this event were monitored by infrasonic arrays up to distance of 3700 km and by the Italian national seismic network at range of hundreds of kilometres. Using state of-the-art propagation modeling, we identify the various seismic and infrasound phases for precise timing of the eruptions and volcanic source characterization. Integrating national seismo-acoustic stations to the global infrasound International Monitoring System network opens new perspectives in volcano monitoring for hazard assessment by providing timely early warning of large eruptions.

Promotional text: Many volcanoes worldwide are poorly monitored. Explosive eruptions produce infrasound that are detected at thousands of kilometers. The use of dense seismo-acoustic networks could provide timely reliable source information of these eruptions to Volcanic Ash Advisory Centers.

P1.1-137 – Infrasound Analysis Associated with the Beirut Explosions Recorded on 4 August 2020

Author: Atef Blel[1]
Co-author: Noureddine Triqui[1]
[1]*Centre National de la Cartographie et de la Teledetection (CNCT), Tunis, Tunisia*
Corresponding Author: blelatef@yahoo.fr

An explosion was reported on the 4th of August 2020 in the Port of Beirut (Lebanon), by IMS infrasound stations. News reported that the explosion was due to a large quantity of ammonium nitrate stored in the port that exploded (equivalent to around 1.1KT of TNT). The infrasonic signal was observed by several infrasound IMS stations, among them the Tunisian one (IS48). Data was processed with DTK-PMCC software to categorize the wave parameters for other infrasound stations.
Promotional text: Tunisian NDC monitor events detected by IMS stations and give a high importance to data analysis (SHI and R) in order to support the Comprehensive Nuclear-Test-Ban Treaty verification regime. Explosion happened in Beirut the 4th of August 2020 was the best challenge event on the 2020.

P1.1-147 – Graphical User Interface "Infrasound Event Analyzer"

Author: Chourouk Mejri ep Boukari[1]
Co-author: Noureddine Triqui[1]
[1]*Centre National de la Cartographie et de la Teledetection (CNCT), Tunis, Tunisia*
Corresponding Author: chourouk.mejri@gmail.com

Infrasound is one of three waveform technologies of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification regime. The International Monitoring System (IMS) network records manmade and natural sources of infrasound signals (bolides, spaceflight activity, sonic booms, volcanic eruptions, quarry blasts, earthquakes...). To identify these sources we need to download and process data, and analysts then have to interpret results. The CTBTO provides us with the needed software, but experience and training are recommended. Our idea is to let analysts enjoy interpreting infrasound data without being obliged to manipulate different software. For this purpose, a Graphic User Interface called "Infrasound event analyzer" is under development by NDC-TN, in which NDC-in-a-Box software (nms_client, DTK-PMCC, DTKGPMCC) are grouped and called on a click.
Promotional text: A GUI "Infrasound event analyzer" allows the use of (nms_client, DTK-GPMC) on a click, is under development by Tunisian NDC in order to reduce the analyst workload and to promote the use of infrasound data in both: test ban verification and civil and scientific application.

P1.1-158 – Validating Infrasound Signal-Parameter Models Using a Global Ground Truth Data Set

Author: Alexandra Nippress[1]
Co-author: David Green[1]
[1]*AWE Blacknest, Reading, UK*
Corresponding Author: alex@blacknest.gov.uk

The celerity-range model used for both association and location in the standard automatic and interactive analysis at the International Data Centre (IDC) of the Comprehensive Nuclear-Test-Ban Treaty Organisation, has not been updated for over 10 years. The NET-VISA automatic association algorithm (Arora et al., 2013) currently providing additional information to IDC analysts, is based on prior probability distributions learned from previous interactive analysis results. Improving the IDC model(s) should improve interactive analysis results, and thus over time improve NET-VISA performance for seismo-acoustic events. Whilst numerical acoustic propagation modelling may be used to provide both range and time dependent priors for signal parameters, ground truth data analysis is necessary for model validation. Using software developed to consistently analyse a global ground truth database, empirical models for celerity, backazimuth and duration have been constructed from 312 detections in the 0.32 – 1.28 Hz passband. The probability distribution for backazimuth is consistent with the NET-VISA backazimuth prior derived using seismo-acoustic events. Our results do not support the IDC model increase in stratospheric signal celerity at a distance of 20°; we look to provide a range-dependent model whose uncertainties reflect the lack of observations at these longer ranges. © British Crown Owned Copyright 2020/AWE

Promotional text: Through validating infrasound signal-parameter models using a global ground truth data set, we aim to improve the infrasound data analysis methods used for nuclear test monitoring. UK Ministry of Defence © Crown Owned Copyright 2020/AWE

P1.1-215 – InfraPy, InfraGA/GeoAc and stochprop: Open Source Software Tools for Infrasound Signal Analysis and Propagation Modelling at Los Alamos National Laboratory

Author: Philip Blom[1]
Co-author: Jeremy Webster[1]
[1]*Los Alamos National Laboratory (LANL), Los Alamos, NM, USA*
Corresponding Author: pblom@lanl.gov

Infrasound research conducted at Los Alamos National Laboratory (LANL) in recent years has included development of tools for signal analysis, propagation modeling, and uncertainty quantification. Many of these tools have been licensed as open source software, made available for download at the LANL Seismoacoustics Github page (https://github.com/LANL-Seismoacoustics), and are utilized by scientists across the globe for a variety of national security, civil, and scientific applications. The InfraPy signal analysis suite includes state-of-the-art detection, association, localization, and yield estimation algorithms accessible through Python-based scripting and notebooks, a command line interface, as well as the InfraView graphical user interface. The InfraGA/GeoAc software is a propagation modeling tool capable of simulating the propagation of infrasonic signals through the atmosphere in the limit of geometric acoustics and includes a number of unique features such as eigenray identification, weakly non-linear waveform calculation, and propagation over realistic terrain. The stochprop library is an in-development tool that includes methods enabling quantification and reduction of propagation uncertainties for infrasound analysis. The capabilities of these tools and their application to recent seismoacoustic events of interest will be presented.

Promotional text: Open-source signal analysis and propagation tools for infrasound, particularly those quantifying uncertainty, support the international explosion monitoring community, promote wider civil and scientific applications, and provide LANL researchers with feedback on algorithms.

P1.1-251 – The State of the Atmosphere Throughout the Seasons: Comparison of Numerical Weather Prediction Models for Infrasound Observations at Regional Distances

Author: Karl Koch[1]
Co-author: Christoph Pilger[1]
[1]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
Corresponding Author: karl.koch@bgr.de

Since the year 2000 the German Aerospace Center (DLR) facility near Heilbronn, Germany, has conducted main engine tests of the European ARIANE-5 rocket. Infrasound signals from these tests have regularly been observed during the last two decades at IMS station IS26 at a range of about 320 km in easterly direction. While a majority of these tests produced signal observations when carried out during the winter season between October and April, there is an almost complete lack

of observations during the summer season. When comparing numerical weather prediction models for summer and winter seasons, or times with detections or non-detections, then these models differ significantly in the sound speed profiles producing either a strong stratospheric duct or a lack thereof. This is also reflected by the effective sound speed ratio, mostly exceeding a value of 1 for detections and less than 1 for non-detections. However, a significant portion of profiles with non-detections, nearly a quarter or 20 out of 88 cases, show a sound speed profile that should enable infrasound signal observations. The reasons for the lack of observations are addressed in this study.
Promotional text: Infrasound signals from ARIANE-5 engine tests over two decades are investigated regarding the state of the atmosphere and the detectability at IMS infrasound station IS26.

P1.1-253 – Rapid Automated Detection, Association and Location of Remote Volcanic Infrasound Using 3-D Ray Tracing and Empirical Climatologies

Author: Rodrigo De Negri[1]
Co-authors: Robin Matoza[1]; Alexis Le Pichon[2]
[1]*University of California, Santa Barbara, CA, USA*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: rsd00@ucsb.edu

Explosive volcanic eruptions produce powerful infrasound signals that are frequently recorded by the International Monitoring System (IMS). We are developing and testing methodologies to detect, locate, and characterize volcanic infrasound globally using data from the IMS. Challenges remain in attributing an infrasound event to a particular volcano, in part because source locations can be offset due to the effect of stratospheric crosswinds. We build on the combined association and location brute-force, grid-search, cross-bearings method of Matoza et al. [2017, 2018], here implementing backazimuth deviation predictions from 3D ray-tracing with empirical climatologies (HWM/MSISE). We are exploring the utility of climatologies rather than operational weather hindcasts for rapid first-order computation (e.g., for near-real-time monitoring, reanalysis of large data archives). With individual event case studies of two similar Volcanic Explosivity Index (VEI) 4 eruptions in Chile (Puyehue-Cordón Caulle volcanic complex on June 4, 2011; and Calbuco volcano on April 22, 2015), and stations up to ~5000 km, we obtain source location improvements of 66 to 89.6%. Here we further test our method using a multi-decadal (2003–2019) dataset of observations of moderate explosive eruptions from volcanoes Yasur, Lopevi, and Ambrym (Archipielago of Vanatu), recorded from 399 to 670 km from I22FR (New Caledonia).
Promotional text: We are building a rapid method to automatically detect, localize, and characterize volcanic infrasound using the IMS network of arrays. In this work we are centered in reducing the source misfit that atmospheric winds introduce on the location method in a robust manner.

P1.1-264 – A Synthetic Study to Determine Adequate Infrasound Network Configurations for Resolving Source Directionality

Author: Alexandra Iezzi[1]
Co-authors: Robin Matoza[1]; David Fee[2]; Keehoon Kim[3]
[1]*University of California, Santa Barbara, CA, USA*
[2]*University of Alaska Fairbanks, Fairbanks, AK, USA*
[3]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: amiezzi@ucsb.edu

Sources including volcanic eruptions and buried explosions have been shown to produce directional infrasound radiation. However, infrasound sensor deployments generally consist of instruments placed on the Earth's surface. Therefore, directional sampling of the radiated acoustic wavefield (especially at angles close to vertical incidence) is generally limited. This insufficient wavefield sampling may bias source size estimates, including mass flow rate for volcanic eruptions or explosion yield. Here

we conduct a synthetic study with local infrasound sensors placed around a directional acoustic explosion source to investigate the configuration of infrasound sensors required to uniquely recover a directional source mechanism estimate. We use finite-difference time-domain methods incorporating rigid topography to obtain the numerical Green's functions for each synthetic station. We invert these synthetics to determine if the prescribed directional source mechanism and source-time function can be retrieved for a variety of station configurations. We consider the influences of environmental factors (wind, temperature, noise), as well as the directionality strength and orientation. The optimal sensor configurations to best estimate acoustic directionality found in this synthetic study will help guide future deployment configurations around active volcanoes and anthropogenic explosions.
Promotional text: This study will help improve our ability to determine yield estimates for underground explosion sources, where infrasound radiation has been shown to be directional. We help bridge the gap between infrasound research on volcanic eruptions and anthropogenic explosions.

P1.1-306 – A Vespagram-Based Approach to Assess Microbarom Radiation and Propagation Models

Authors: Ekaterina Vorobeva[1]; Marine De Carlo[2]; Alexis Le Pichon[3]; Patrick Joseph Espy[1]; Sven Peter Näsholm[4]
[1]*Norwegian University of Science and Technology, Norway*
[2]*Laboratoire d'Océanographie Physique et Spatiale, CNRS, France*
[3]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[4]*Norwegian Seismic Array (NORSAR), Kjeller, Norway*
Corresponding Author: peter@norsar.no

This study presents a vespagram-based approach for comparison between infrasound data recorded at the ground and simulated microbarom soundscapes in multiple directions simultaneously. Data recorded during 2014-2019 at the IS37 station in Bardufoss, Norway, have been processed in the framework of velocity spectrum analysis in order to generate images that present a signal power depending on time and direction (vespagrams). Calculations were performed for several frequency bands within the 0.1 - 0.6 Hz range. The modelled microbarom soundscapes were smoothed to account for the frequency-dependent array resolution. The infrasound data processed and modeled microbarom soundscapes were compared in three different aspects: i) azimuthal distribution of dominating signal, ii) signal amplitude, and iii) ability to track atmospheric changes during extreme events such as sudden stratospheric warmings (SSW). The results reveal good agreement between model and data and demonstrate the ability of vespagrams to monitor the microbarom azimuth distribution, amplitude, and frequency on a seasonal scale, as well as changes during SSWs. The presented vespagram-based approach is computationally low-cost and can uncover microbarom source variability. There is also potential for near-real-time diagnostics of the atmosphere and microbaroms, especially when applied to multiple stations, e.g. exploiting the CTBTO International Monitoring System network.
Promotional text: Infrasound waves originating in the ocean, propagating through the atmosphere, and recorded by the CTBTO station are compared to the model via the new approach. Results show good agreement. The approach has potential for near-real-time diagnostics of the atmosphere.

P1.1-399 – The Global and Coherent Infrasound Wavefield: Recent Advances in Reprocessing the Full International Monitoring System Infrasound Data

Authors: Patrick Hupe[1]; Lars Ceranna[1]; Alexis Le Pichon[2]
[1]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: patrick.hupe@bgr.de

We present recent advances and results of reprocessing the IMS infrasound dataset from its beginning until early 2021. A new implementation of the Progressive Multi-Channel Correlation (PMCC) algorithm enables characterization, with a single processing run, of coherent noise in logspaced frequency with one-third octave bands from 0.01 to 5 Hz. Such an array processing algorithm enables better characterization of all received signals in their wave parameter spaces (e.g. frequency–azimuth, frequency–trace velocity). This, in turn, permits more accurate signal discrimination and source and propagation studies. The latest comprehensive reprocessing of the IMS infrasound database covers the period from January 2003 to December 2020; in the meantime, the number of stations has increased from 30 to 53. The obtained results clearly indicate a continuous spectrum of coherent signals at IMS stations within the 0.01 to 5.0 Hz frequency range, as well as the wave parameters' relation to middle atmosphere dynamics. Also, more sources are identified when comparing the recent results with those of previous reprocessing approaches or the standard IDC products.
Promotional text: Our comprehensive dataset (up to 18 years) serves as the reference for a microbarom model validation (abstract by De Carlo et al.). It also opens up avenues for further studies (abstract by Hupe et al.) presenting tailored products for atmospheric and civilian applications.

P1.1-401 – Characterization of the 4 August 2020 Beirut Explosion from the Infrasound Component of the IMS Network

Authors: Julien Vergoz[1]; Christophe Millet[1]; Yoann Cano[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: julien.vergoz@cea.fr

The 4 August 2020 tragic Beirut ground truth explosion is of great interest to test the infrasound component of the IMS network, especially in terms of localization accuracy and energy estimation. Although the event was detected by five infrasound IMS stations located from 2400 km (I48TN, Tunisia) to 6200 km (I11CV, Cape Verde), the early location capability from such a sparse network remains limited. Indeed, the spatial distribution of the remote detecting stations tainted by variable background noise levels, coupled with the relatively high uncertainties associated to the atmospheric parameters in the middle atmosphere, make the accurate localization estimation of such medium size events very challenging. We will show in this presentation that even if meteorological institutes can now provide high spatial and time resolution operational products (1h in time and 0.25° in space) at a global scale up to 80 km altitude, the final localization uncertainties remain quite high using infrasound-only data. Examples of full-wave modelling performed from ECMWF analysis and forecasts products, that the IDC distributes to Member States, will be shown to illustrate that point. Such model effects on energy estimation will also be quantified and discussed.
Promotional text: Infrasound analysis of the 4 August 2020 tragic Beirut explosion.

P1.1-416 – Construction and Evaluation of a Statistical Model of Seasonal Forecasts in Cameroon

Author: Hermann Nana[1]
Co-author: Roméo Stève Tanessong[2]
[1]*University of Yaounde I, Cameroon*
[2]*University of Dschang, Cameroon*
Corresponding Author: nanahermann100@yahoo.com

The objective of this study is to build and then evaluate a statistical model of seasonal forecasts in Cameroon. A study was carried out in the five agro-ecological zones of Cameroon with the test stations of Kaélé, Meiganga, Nkongsamba, Yaoundé and Kribi. This study consisted of developing statistical forecast models at each of these stations which were then evaluated first over their calibration period (1958-1987), then over an earlier period (1989-1993). It emerges from this evaluation that the sea surface temperatures so far used during the PRESACs explain "roughly" the rainfall in Cameroon and especially in the cities of Yaoundé and Kribi where the multiple correlations between the sea surface temperature and rainfall indices are 0.70 and 0.71 respectively. It also follows that the Hit Skill Score and the rate of coincidence between forecast and observed rainfall indices vary from 65% to 85% and 76.66 % to 90% respectively. No model has false alarms. Strong connections between rainfall in Cameroon and the oceanic areas of the Atlantic coast of Africa located on the course of the African monsoon, the engine of rainfall in the region have been established. These results argue in favor of exploring other predictors to improve predictions.

Promotional text: This study then allows to know what will be the rainy season to come, through a qualitative evaluation of the seasonal accumulation of precipitations. This makes it possible to define strategies for the management of natural resources.

P1.1-458 – Observing Military Aircraft Activity with the Romanian Infrasound Arrays

Author: Daniela Ghica[1]
Co-authors: Constantin Ionescu[1]; Mihaela Popa[1]
[1]*National Institute for Earth Physics (NIEP), Magurele, Romania*
Corresponding Author: daniela_ghica@yahoo.com

Presently, National Institute for Earth Physics operates two infrasound stations deployed on the Romanian territory: IPLOR 4-element array of 0.6 km aperture, and, under cooperation with AFTAC (USA), BURARI 6-element array of 0.7 km aperture. As many military bases are deployed across Europe and Near East region, signals from supersonic aircraft activity are detected routinely at the Romanian infrasound stations. These signals are observed from short/local ranges (140 km) to long-distance ones (2200 km). Several directions of interest were identified: NW (North Sea, Germany), NNW (Norwegian Sea, Northern Norway), NNE (NE Ukraine-NW Russia), SSE (Aegean Sea), SE (Turkey, Sinai Peninsula). Moreover, the two arrays frequently observe supersonic jets flying from military bases located in Romania. Sonic booms generated by military aircraft could be localized by cross bearing the detections of IPLOR and BURARI arrays. The information released on military exercises and LEB bulletins is used to validate the locations. At local distances, the sonic boom appears as an infrasonic pulse dominated by high frequencies (above 1 Hz), while, for long-ranges, lower frequency drops below 1 Hz as the higher frequency components are rapidly attenuated. Statistical analysis of wave parameters (trace velocity, azimuth, frequency, amplitude) shows seasonal and daily variations.

Promotional text: As many military bases are deployed across Europe and Near East region, signals from supersonic aircraft activity are detected routinely at the Romanian infrasound stations IPLOR and BURARI. These signals are observed from short ranges (140 km) to long-distance ones (2200 km).

P1.1-464 – Detection and Properties of Local Artillery Infrasound

Authors: Quentin Brissaud[1]; Tormod Kværna[1]; Kamran Iranpour[1]; Tina Kaschwich[1]; Idar Dyrdal[2]
[1]*Norwegian Seismic Array (NORSAR), Kjeller, Norway*
[2]*Norwegian Defence Research Establishment (FFI), Kjeller, Norway*
Corresponding Author: quentin@norsar.no

Acoustic-wave detection from man-made sources like explosions and artillery is of interest both for civilian and military purposes. Infrasound propagation from surface sources is controlled by a complex interplay between source location, winds, atmospheric attenuation, and topography. The seasonal and stochastic variability of stratospheric and tropospheric winds is known to play an important role in the detectability of infrasound on the ground. In particular, large wind-intensity variations occur between summer and winter months. However, the lack of high-quality observational datasets with good temporal coverage throughout the year limits our understanding of the correlations between source characteristics, range-dependent atmospheric properties, and topography. Here, we take advantage of an extensive set of artillery exercises, conducted by the Norwegian Armed Forces in southern Norway throughout 2020, to constrain the detectability and wave properties at local distances. Up to 70 km distance, signals are generally observed when the atmospheric models include stronger lower-tropospheric winds (1-5 km altitude) blowing in the direction of propagation. When cross winds dominate the wind field, low-amplitude infrasound arrivals are still observed in the acoustic shadow zone while not predicted by ray-tracing simulations, highlighting both model and propagation uncertainties introduced by small-scale wind heterogeneities and diffraction effects.

Promotional text: Artillery shots excite acoustic waves travelling over at large distances. Characterizing infrasound sources is crucial for civilian and military purposes. We perform an extensive investigation of military exercises in Norway to derive the main property of artillery infrasound.

P1.1-491 – Infrasound Propagation Simulations Using Atmospheric Fields from High Resolution Global Models Resolving Gravity Waves

Author: Constantino Listowski[1]
Co-authors: Claudia Stephan[2]; Alexis Le Pichon[1]; Alain Hauchecorne[3]; Ulrich Achatz[4]; Gergely Bölöni[4]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[2]*Max Planck Institute for Meteorology, Hamburg, Germany*
[3]*Laboratoire Atmosphères, Observations Spatiales (LATMOS), France*
[4]*Goethe-Universität Frankfurt, Germany*
Corresponding Author: constantino.listowski@cea.fr

Small-scale atmospheric perturbations known as gravity waves (GW) are critical to infrasound propagation simulations as they alter the propagation path of the waves, causing detections at infrasound stations that remain unexplained when only large scale atmospheric features are considered. Therefore, it is important to investigate ways of accounting for these perturbations in the atmospheric fields prescribed in propagation models. Here, we use modelled atmospheric fields obtained in the framework of the Dynamics of the Atmospheric General Circulation Modeled on Nonhydrostatic Domains (DYAMOND) project. This international project, initiated by the Max Planck Institute for Meteorology (MPIM) and the University of Tokyo, describes a framework for the intercomparison of high-resolution global atmospheric models. It mainly focuses on tropospheric weather, but some models were run with a high enough top so that GW are resolved up to the stratosphere. Starting with different configurations of the Icosahedral Non-hydrostatic (ICON) model, we explore how differences in infrasound-related parameters (azimuth deviation, shadow zone, celerity) derived using a ray-tracing tool relate to differences in the resolved tropospheric and stratospheric wind and temperature fields. Lidar observations are used to assess the modelled fields and to bring ground-truth atmospheric specification for infrasound propagation simulations.

Promotional text: The verification regime of the Comprehensive Nuclear-Test-Ban Treaty requires to use the best possible tools to detect and analyse events of interest. Using infrasound observations for analysis demands very good knowledge of the middle atmosphere and its small-scale dynamics.

P1.1-522 – A Novel Approach for the Reconstruction of Microbarom Soundscapes

Authors: Olivier Frederik Constantinus Den Ouden[1]; Pieter Smets[2]; Jelle Assink[1]; Läslo Evers[1]
[1]*Royal Netherlands Meteorological Institute (KNMI), De Bilt, the Netherlands*
[2]*Delft University of Technology, Delft, the Netherlands*
Corresponding Author: olivierdenouden@gmail.com

In this study, a comparison is made between in-situ infrasound recordings in the microbarom band and simulations using a microbarom source model. The recordings are obtained by the 'Infrasound-Logger' (IL), a miniature sensor that has been deployed as biologger near the Crozet Islands in January 2020. The sensors provide barometric and differential pressure observations that have been obtained directly above the sea surface. A method is introduced to appropriately account for all microbarom source contributions surrounding the IL, as the full field consist of multiple spatially distributed sources. In this method, range and frequency-dependent losses due to propagation in the atmosphere are accounted for. While the method relies on several assumptions, a good agreement can be observed: the reconstructed soundscape is found to be within ± 5 dB for 80% of the measurements in the frequency band of 0.1-0.3 Hz. The development of microbarom soundscapes is essential for a better understanding of the ambient infrasonic noise field. Earlier work has shown that such knowledge is useful for infrasonic remote sensing of the upper atmosphere. Moreover, insights in the ambient noise field will improve the monitoring of natural hazards and the verification of the Comprehensive Nuclear-Test-Ban Treaty.

Promotional text: In this study we propose a new method to reconstruct the microbarom sourcefield, and compared it with in-situ infrasound recordings by the 'Infrasound-Logger' (IL). The IL is a miniature biologger that has been deployed near the Crozet Islands. Such comparisons are unprecedented.

P1.1-547 – Microbarometer Arrays for the Monitoring of Extreme Weather in a Changing Climate

Author: Jelle Assink[1]
Co-authors: Läslo Evers[1]; Arnoud Apituley[1]; Bram van 't Veen[1]; Sander Tijm[1]
[1]*Royal Netherlands Meteorological Institute (KNMI), De Bilt, the Netherlands*
Corresponding Author: jelle.assink@knmi.nl

Microbarometer arrays are used for the verification of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) using infrasound waves. In addition, the microbarometers also measure pressure variations that are due to various meteorological phenomena with a resolution that exceeds that of typical barometers. The value of these high-resolution observations for the monitoring of extreme weather is discussed here, focusing on two recent extreme weather events in the Netherlands. Data from a dense observational network that includes lidar facilities and the Dutch microbarometer array network is compared to forecasts from global and regional weather forecast models to assess the forecast skill of the state-of-the-art weather models. The first-order agreement suggests that microbarometer arrays could provide valuable data for the development of next-generation weather forecast models. Such developments are useful for Early Warning Centers that report on severe weather outbreaks that can be disruptive for society and which are expected to occur more frequently in a changing climate.
Promotional text: This presentation demonstrates that the infrasound technology, as a civil and scientific application, could aid in the forecasting of extreme weather events that are predicted to occur more frequently in a changing climate.

P1.1-588 – Long-Range Infrasound Detections from Explosions that Occurred in the Mediterranean Area in 2020 as Tools to Evaluate the IMS Network Detection Capability

Author: Sandro Matos[1]
Co-authors: Nicolau Wallenstein[1]; Paola Campus[2]
[1]*Instituto de Investigação em Vulcanologia e Avaliação de Riscos (IVAR), Azores, Portugal*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: sandro.b.matos@azores.gov.pt

IS42 is one of International Monitoring System (IMS) infrasound stations, located in the Azores islands in the North-Atlantic Ocean. Stromboli volcano is located in a small Italian island in the Mediterranean Sea. It is probably the world's best-known volcano due its spectacular basaltic explosions interspersed by lava fountains up to 250 m occurring every ≈10 minutes. Following the far-field characterization of its continuous explosive activity on infrasound-based analysis, we present here IS42 detections at a source-to-receiver distance of ≈3,700 km and a back-azimuth of ≈76°. Beirut, located on the Mediterranean coast, is the capital and the largest city of Lebanon. On 4th August 2020 at 15:08 UTC, the city harbour was almost completely destroyed by an enormous explosion caused by the combustion of 2700t of ammonium nitrate. This event was detected in various IMS infrasound stations, including IS42, at source-to-receiver distances ranging from approximately 2,400 km to 8,900 km. We present here the IS42 infrasound detections from this event, as well as from other IMS infrasound stations and compare the detections obtained with the events listed in the Reviewed Event Bulletin (REB) of the CTBTO, in order to evaluate the potential of the IMS network the IMS network capability.
Promotional text: The use of ground-truth data from natural and man-made atmospheric extreme events offers the opportunity to evaluate long-range detection capabilities of the IMS infrasound network. We present here an IS42 study case for the 2020 Stromboli Volcano and Beirut Harbor explosions.

P1.1-626 – Characterization of the Coherent Infrasound Sources Recorded by the Infrasound International Monitoring System Station IS48 in Tunisia (Mines Quarries)

Authors: Abdelouaheb Agrebi[1]; Andry Ramanantsoa[2]; Gerard Rambolamanana[1]; Eddy Harilala Rasolomanana[3]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Institute and Observatory of Geophysics of Antananarivo (IOGA), Madagascar*
[3]*Université d'Antananarivo, Ecole Polytechnique, Antananarivo, Madagascar*
Corresponding Author: abdelouaheb.agrebi@ctbto.org

The I48TN is one of the 60 International Monitoring System (IMS) stations of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) characterized by its location in the heart of the IMS Infrasound network (Figure 1.a). The ability of the IMS infrasound network to detect atmospheric nuclear explosions and other signals of interest is strongly dependent on station specific ambient noise. This ambient noise includes both incoherent wind noise and real coherent infrasonic waves. This abstract will focus on defining and characterizing the mines and quarries in the region as the most important real coherent infrasonic noise to I48TN in order to provide the infrasound data analyst with the most important local coherent infrasound sources in the region (mines and quarries) as recorded by I48TN and also to demonstrate how useful is the synergy between Infrasound and seismic data for the characterization of the acoustic sources. DTK_GPMCC, and DIVA software are used to perform this study (Cansi, 1995; Le Pichon et al., 2010). Also, Geotool software from the International Data Centre (IDC) will be used to analyse KEST seismic data. The result of this study will allow to characterize the most important coherent local infrasound sources (mines and quarries) for I48TN.
Promotional text: I48TN and KEST stations are used to define and characterize mines and quarries in the region showing the synergies between Seismic and Infrasound technologies and the propagation of infrasound data from the coherent infrasound sources in the region.

P1.1-627 – Deep Learning for Converting Noise into Knowledge

Author: Christophe Millet[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: christophe.millet@cea.fr

While awaiting signals from a nuclear test, the International Monitoring System (IMS) routinely detects many events that are attributed to atmospheric processes and referred to as perturbators or noise. These events, known to cause false detections, are an important source of difficulty in the network processing operated at the International Data Center (IDC). Because many thousands of events are recorded per day, recent efforts have been made in developing probabilistic inference for network processing and more recently, for estimating the energy. All these approaches, however, are based on priors that are poorly constrained, and/or extremely simplified propagation models, that are known to exhibit persistent shortcomings. In this work, we introduce a new hybrid framework to derive prior probability models from waveform modeling and take advantage of events accumulated in the analyst-reviewed bulletin. This approach is based on using current state-of-the-art propagation models in combination with a data-driven machine learning tool to model the remaining residual that is hidden in data. This approach presents two significant innovations: (1) the capability of converting perturbators into information, thereby providing a physical basis for the priors and (2) the opportunity to incorporate on a daily-basis additional atmospheric data in the priors.

Promotional text: In this work, it is shown how unsupervised learning (i.e. learning without labeled training data) can be used to extract information from signals of the IMS that can be translated into knowledge for better constraining automated tasks at the IDC.

P1.1-650 – Comparison of Forward and Backward Source–Receptor Sensitivities for Atmospheric Inverse Modelling Using the HYSPLIT Model with the Cross-Appalachian Tracer Experiment (CAPTEX) Field Experiment Measurements

Authors: Tianfeng Chai[1]; Mark Cohen[2]; Fong Ngan[2]
[1]*University of Maryland, College Park, Maryland, USA*
[2]*National Oceanic and Atmospheric Administration (NOAA), USA*
Corresponding Author: tianfeng.chai@noaa.gov

Based on observations from monitoring stations or other platforms, unknown atmospheric pollutant emission sources, including source location, strength, and temporal variations, can be estimated using inverse modeling techniques. In such applications, 3D-particle Lagrangian dispersion models are usually employed, and the source-receptor sensitivities are calculated in either forward or backward modes for the source term estimation. While specifics of a given application may suggest a preference for one mode over the other, both forward and backward approaches can generally be applied for the inverse modeling. However, differences are often found in the inversion results between analyses based on forward and backward methodologies. In this study, we use the Cross-Appalachian Tracer Experiment (CAPTEX) field experiment as a test case to compute the source-receptor sensitivities between the known sources and air samples collected at 84 measurement sites. The differences between the forward and backward sensitivities calculated using the HYSPLIT model will be presented. The impact of the differences between the two approaches on the source term estimation results will be discussed. In addition, the underlying causes of the sensitivity discrepancies between the forward and backward approaches will be investigated and discussed.

Promotional text: The atmospheric radionuclide observations from CTBTO IMS network are often used to estimate the sources using inverse modeling techniques. In this study, we compare forward and backward source-receptor sensitivities for atmospheric inverse modeling using the HYSPLIT model.

P1.1-672 – Unusual Infrasound Observations from the August 2020 Beirut Explosion

Author: Jelle Assink[1]
Co-authors: Roger Waxler[2]; Philip Blom[3]; Läslo Evers[1]; Shahar Shani-Kadmiel[1]; Yochai Ben-Horin[4]
[1]*Royal Netherlands Meteorological Institute (KNMI), De Bilt, the Netherlands*
[2]*National Center for Physical Acoustics, University of Mississippi, MS, USA*
[3]*Los Alamos National Laboratory (LANL), Los Alamos, NM, USA*
[4]*Soreq Nuclear Research Center, Yavne, Israel*
Corresponding Author: jelle.assink@knmi.nl

On 4 August 2020, a warehouse of ammonium nitrate exploded in Beirut, Lebanon, leading to loss of life and property. Infrasonic signals from this event have been detected across the Middle East, Europe and North Africa. The furthest IMS station that detected the signal was IS11 (Cape Verde) at over 6000 km distance. The features of the observed infrasonic signals were unusual for the time of year. (1) Signals with tropospheric celerities were observed at IS26 and IS48, the nearest IMS arrays to the west and northwest, as well as the national arrays in Hungary (PSZI) and Romania (IPLOR). (2) At IS26 and PSZI, curious trace velocity trends were observed, starting at high values and decreasing along the wave train, contrary to what is typically observed. (3) The fastest arrivals at IS26 and PSZI appear to have significant back azimuthal scatter. These observations suggest that the propagation conditions were more complex than a single stratospheric duct which is typical for mid-summer conditions in the Northern Hemisphere. It is hypothesized that the tropospheric phases interacted significantly with topography. This hypothesis is supported by wind and temperature forecasts derived from numerical weather prediction models. An analysis of the propagation conditions is presented.
Promotional text: The tragic explosion that occurred in Beirut, Lebanon on 4 August 2020 generated infrasound that could be observed over 6000 km away. Our analysis of this dataset helps to further improve our knowledge of infrasound and its use in verification monitoring.

T1.2 The Solid Earth and Its Structure

Highlights

Velocity Models

Most monitoring agencies rely on fast, distance-dependent, one dimensional (1-D) earth models to calculate seismic event locations quickly and in near real time. RSTT, as presented in P1.2-120, is a seismic velocity model and computer software package that captures the major effects of three dimensional (3-D) crust and upper mantle structure on regional seismic travel times, while still allowing for fast prediction speed (milliseconds). Validation of the updated RSTT model demonstrates a significant reduction in median epicentre mislocation as well as more accurate error ellipses.

O1.2-165 and O1.2-412 analysed P wave data to improve velocity models in the Middle East. O1.2-165 retrieved detailed models down to the lower mantle in the Middle Eastern region using a set of reliable regionally observed teleseismic P arrival times from the International Seismological Centre-EHB bulletin (Engdahl et al., 1998). The current inversion results are consistent with the previous regional tomographic studies. O1.2-412 gathered a large data set of seismic travel times recorded in Israel and nearby countries. A new high resolution model for crustal seismic velocities in Israel is to be integrated into the RSTT model and procedure to enhance CTBT monitoring capabilities in the Middle East. In P1.2-041, the first continental-scale shear wave velocity model of the lithosphere was constructed based on the joint analysis of ambient seismic noise and earthquake data recorded by approximately 1529 seismic stations in and around Africa. Ambient noise cross-correlation and earthquake two-station methods were applied to retrieve the Rayleigh wave group and phase velocity dispersions, which are jointly inverted for a new 3-D shear wave velocity model.

The study presented in P1.2-368 used results from the Continental Deep Drilling Programme (KTB) in Germany, where crustal rocks have been drilled down to 9 km depth and several active seismic studies have been performed in the surrounding area. A new shear wave velocity model of the upper crust of the region shows velocity variations at short scales that correlate well with the geology of the region. Seismic ambient noise data were used to image the upper crustal structure around the KTB drilling site. The results are well matched with the surface geology and improve the understanding of the complex structure of the shallow crust.

P1.2-369 analysed the difference between the velocity of Rayleigh and Love waves to determine radial anisotropy beneath the Zagros belt of the Iran Plateau. The continuous ambient noise data are processed to image two dimensional (2-D) tomographic dispersion maps, and a quasi-3-D shear wave velocity and radial anisotropy model are calculated by joint inversion of the Rayleigh and Love local phase velocity dispersion curves using the Bayesian Markov Chain Monte Carlo (MCMC) inversions method. Radial anisotropy patterns suggest ductile shear zones in the middle to lower crust beneath the Zagros belt.

Events Parameter Determination

Automatic depth determination at teleseismic distance remains a challenge: the depth phases (pP, sP) reflected on the free surface are sometimes difficult to determine, especially for events of intermediate magnitude (Mw <5). O1.2-277 characterized uncertainties associated with teleseismic depth determination and proposed two complementary methods: (1) a cepstral analysis to extract the pP-sP reflected waves in the P-coda from their phase's similarity with the direct P wave and (2) an envelope stacking procedure aiming to distinguish these secondary arrivals from their energetical contents. The goal is to improve signal to noise ratio and automatically identify coherent depth phases. The results were confronted with a set of well-determined regional depths in the Nepalese Himalayas, a region of high topography and relatively shallow seismicity.

P1.2-155 examined the consistency between the IDC and the ISC magnitudes for earthquakes in East Africa between 2000 and 2020. Based on body wave magnitude (mb), surface wave magnitude (MS) and local magnitudes, conversion equations between magnitudes were constructed. P1.2-201 derived formulas and determined station magnitude corrections for local earthquake magnitude (ML and MLv) in northern Thailand.

Information on moment tensors is important for understanding the origin of events (e.g. explosions, natural and induced earthquakes). The calculation of moment tensors for weak seismic events is challenging. The authors of P1.2-659 reanalysed two methods of retrieving moment tensors: (1) inversion of amplitudes of P and S waves and (2) inversion of three-component full waveforms, complemented by first-motion polarities. The analysis is performed on the basis of data from two weak earthquakes on the Slovakia–Ukraine border in 2020.

Earthquake and Fault Monitoring

Monitoring and understanding earthquakes was a major theme under Topic 1.2. O1.2-238 described the monitoring of sub-seafloor deformation in a plate subduction zone in real time, continuous mode, using the seafloor geodetic network in the Nankai Trough in Japan. To understand slip behaviour along the fault, the aim is to obtain data on seafloor displacement and sub-seafloor structure, which are needed to transform a surface displacement into a fault displacement. Recent studies reveal that surface displacements resulting from fault slips have a wide spectrum of frequency, from a regular earthquake (~10 Hz) to a long term slow slip (~months). O1.2-091 described 3-D dynamic earthquake fracture simulations for the nonplanar and heterogeneously stressed Main Marmara Fault in Turkey, using the 3-D finite element PyLith code. The study attempts to generate realistic earthquake scenarios using physics-based approaches considering past earthquakes, slip rates on different fault segments from geodesy, 3-D fault geometry and heterogeneity of interseismic coupling from seismicity and geodesy.

P1.2-053 and P1.2-272 described work in Bolivia to improve seismic hazard assessments for various regions of the country. Waveforms from 80 earthquakes were analysed to obtain the pseudo acceleration, velocity and displacement spectra. The probabilistic seismic hazard map (PSHBO-2019) is the first map to integrate all variables and is available for Bolivia.

P1.2-060 analysed seismic hazard estimates for the Himalayan State of Uttarakhand in terms of peak ground acceleration. Two next-generation attenuation models were used. P1.2-325 describes the installation, site classification, local seismicity reports and velocity structure studies of a broadband seismic network in Myanmar, in collaboration with the Earth Observatory of Singapore.

P1.2-094 described a joint project with the long term goal of reducing seismic hazard and risk in Saudi Arabia. The analysis started by using time–domain full waveform moment tensor inversion and coda-envelope-derived amplitude measurements to solve for earthquake source mechanisms, moment magnitudes and source type. Work in the United Arab Emirates was highlighted in P1.2-538, which described a strong motion network, and in P1.2-544, which examined the post-seismic slip following intermediate magnitude earthquakes and found that it is approximately 40 per cent of the coseismic moment. The authors propose that the variation in postseismic slip with moment suggests that earthquakes may not be self-similar.

P1.2-503 described the occurrence and extent of earth fissures in southern Malawi. P1.2-357 performed 3-D tomography of the crustal structure of the central part of Madagascar. P1.2-171 addressed possibilities to better monitor seismicity in Nigeria, including infrasound monitoring. P1.2-341 analysed gravity data collected in the area west of Khartoum, Sudan.

P1.2-367 detected irregularities in the seismicity of western and central Uzbekistan and raised the possibility that the 1976 and 1984 Gazly earthquakes were partly triggered by a combination of natural processes and technological triggers, including the operation of gas fields and two nearby nuclear explosions in 1966 and 1968. P1.2-545 described the seismological network of Nepal that has become denser following the 2015 Gorkha earthquake. The network is now equipped with broadband and short-period seismometers that allow better location and seismological research.

P1.2-188 analysed foreshock activity in the Iranian plateau from 1968 to 2018. Among the 165 main shocks with $M \geq 5.5$, 18 per cent were preceded by at least one foreshock within 30 days and 20 km. Foreshock occurrence is correlated with faulting type and depth, but not with the magnitude of the main shock.

P1.2-227 presented a seismicity assessment in the central part of the Baikal Rift Zone in Russia. The concept of "seismic background" allows comparisons with other regions and the study of variations over time.

P1.2-254 investigated seismic attenuation characteristics of the Canadian portion of the northern Appalachians. The coda-Q value was determined using 389 earthquakes ($1.8 \leq M \leq 3.9$) recorded in New Brunswick from 1985 to 2020. Ongoing mapping of coda-Q using the Canadian National Seismograph Network stations is planned in order to contribute to more accurate seismic hazard models.

P1.2-631 estimated the occurrence of suspect instrument intervals. It collected time histories of noise measurements obtained near midnight (to eliminate diurnal variations) and found anomalous time intervals that represent 13 per cent of the total inspected time range. Various methods can be applied to identify issues with seismic instrumentation and calibration.

O1.2 The Solid Earth and Its Structure Abstracts of Oral Presentations

O1.2-091 – 3-D Dynamic Earthquake Rupture Simulations in the Sea of Marmara

Authors: Yasemin Korkusuz Öztürk[1]; Nurcan Meral Özel[2]; Ali Özgün Konca[1]
[1]*Bogazici University, Istanbul, Turkey*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: yaseminkrksz@gmail.com

The center of the Sea of Marmara, the region between the locations of 1912 Mürefte and 1999 Izmit Mw7.4 earthquakes, is prone to creating a large earthquake. The main objective of our study is to determine 3D dynamic earthquake rupture scenarios, considering non-planar and heterogeneous stress distribution in the Sea of Marmara. In this study, it is the first time that we attempt to generate realistic earthquake scenarios by putting constraints on initial stress on the fault using regional stress from earthquake focal mechanisms, in addition to stress release during past earthquakes and strain accumulation during interseismic period using geodetical measurements on slip-rate and locking depth at various segments. We use 3D Finite Element Method (PyLith) for dynamic earthquake simulations and tetragonal mesh for better smoothing at the fault bends, which allows us to implement nonplanar fault geometry and initial stress heterogeneity using slip-weakening friction law. We place constraints on initial shear stress from geodetic and seismic studies of locking depth and interseismic strain accumulation. We consider more than a hundred rupture scenarios and calculate slip distribution, rupture velocity and moment magnitude in addition to slip-rate and traction on the fault surface, and displacement and velocity on the ground surface.

Promotional text: We derive 3D dynamic earthquake fracture simulations for the nonplanar and heterogeneously stressed Main Marmara Fault which is prone to a large event and located very close to Istanbul Metropolitan.

O1.2-165 – P Wave Arrival-Time Tomography of the Middle East

Authors: Ebru Bozdag[1]; Manawaduge Susini Desilva[1]; Guust Nolet[2]; Rengin Gok[3]; Ahmed Ali[4]; Yahya Tarabulsi[4]
[1]*Colorado School of Mines, CO, USA*
[2]*GeoAZUR, Université de Nice Sophia Antipolis, France*
[3]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
[4]*Saudi Geological Survey, Saudi Arabia*
Corresponding Author: bozdag@mines.edu

High-resolution tomographic images of the Middle Eastern region are essential to accurately locate ground motion events during nuclear monitoring programs. The purpose of this study is to retrieve detailed models down to lower mantle beneath the Middle Eastern region using a set of reliable regionally observed teleseismic P arrival times from the ISC-EHB bulletin (Engdahl et al., 1998). Our current inversion results are consistent with the previous regional tomographic studies. In checkerboard tests of cell dimension as low as ~ 2.4∘ (~ 280 km at surface) are well recovered down to a 1000 km depth beneath the Anatolian plateau where we currently have the densest coverage with ISC data. The Caucasus region and northern parts of the Iranian plateau shows good recovery of ±4% Vp perturbation amplitudes at depths ~ 70-135 km. There is fair recovery for a minimum of ~ 2.4∘ cell size beneath the Iranian Plateau, Zagros mountain region, Persian Gulf, and northeast Iraq. We are able to further improve coverage especially down to lithospheric depths within the Arabian peninsula using first arrival times measured from waveform data collected from regional networks. The ultimate goal is to perform full-waveform inversion of the region constrained by the constructed P-wave model.

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Promotional text: Seismic Imaging of Middle Eastern crust and mantle.

O1.2-238 – Monitoring Sub-Seafloor Deformation in Plate Subduction Zone

Authors: Shuichi Kodaira[1]; Eiichiro Araki[1]; Takane Hori[1]; Gou Fujie[1]; Ayako Nakanishi[1]
[1]*Japan Agency for Marine-Earth Science and Technology, Yokosuka, Kanagawa, Japan*
Corresponding Author: kodaira@jamstec.go.jp

Fault rupture in a subduction zone often causes devastating earthquake and tsunami hazards. Therefore, understanding a slip behavior along the fault is a crucial scientific topic and a deeply socially relevant problem. To understand the slip behavior along the fault, there are two kinds of essential geophysical datasets. One is seafloor displacement as a surface response of a fault slip, and the other is the sub-seafloor structure, which is needed to transform a surface displacement to a fault displacement. Recent studies reveal that surface displacements due to fault slips show a wide-spectrum of their frequency, from a regular earthquake (~10 Hz) to a long-term slow slip (~months). To monitor the entire spectrum of the fault slip, monitoring the displacement with a seismo-geodetic band in real-time continuously is necessary. And also, to transform the displacement to the slip along the fault, it is essential to know a realistic structure of a medium (lithospheric structure) in the subduction zone. JAMSTEC is conducting an integrated geophysical project to establish a real-time continuous seafloor geodetic network in the Nankai Trough, Japan, and construct a three-dimensional structural model using seismic data. We will present an outline and recent results of the project in this presentation.

Promotional text: The sensing and modeling the seafloor displacement can be utilize other kind of monitoring of signal propagating through the earth and/or the ocean, such as signals from Nuclear-Test-Ban.

O1.2-277 – Teleseismic Depth Determination, Techniques and Uncertainties: A Himalayan Case Study

Authors: Marine Laporte[1]; Jean Letort[2]; Laurent Bollinger[1]; Lok Bijaya Adhikari[3]; Yoann Cano[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[2]*Institut de recherche en astrophysique et planétologie, Toulouse, France*
[3]*National Earthquake Monitoring & Research Centre, Katmandu, Nepal*
Corresponding Author: marine.laporte@cea.fr

Accurate estimates of the depth of seismic events allow determining whether they are associated to a given tectonic structure. It is also a good discriminator between earthquakes and explosions. However, automatic depth determination at teleseismic distance remains a challenge: the depth phases (pP, sP), reflected on the free surface, are sometime difficult to pick in the teleseismic signal. This is particularly true when the events are intermediate magnitudes (Mw<5), and fall at shallow depths in complex tectonic environments. To overcome that challenge, we implement two teleseismic depth estimation methods: (1) a cepstral analysis allowing to extract the pP-sP reflected waves in a the P-coda from their phase's similarity with the direct P wave and (2) an envelope stacking procedure aiming to highlight these secondary arrivals from their energetical contents. These two complementary methods allow improving signal over noise ratios and automatically identifying coherent depth phases among the thousands of teleseismic stations and arrays available from global teleseismic networks, including those of the International Monitoring System monitored by CTBTO. We confront our results to a set of well determined regional depths determined from a dense temporary network deployed in the Nepalese Himalayas, a region of high-topography and relatively shallow seismicity.

Promotional text: Our study characterizes uncertainties associated to teleseismic depth determination using global teleseismic networks, including the IMS. We propose solutions to overcome the limitations coming from depth phase identification for investigating the structure of tectonic plates.

O1.2-412 – A Crustal P Wave Velocity Model for Israel to Improve IMS Capabilities in the Middle East

Authors: Lewis Schardong[1]; Yochai Ben-Horin[2]; Alon Ziv[1]; Stephen Myers[3]; Hillel Wust-Bloch[1]; Michael L. Begnaud[4]; Brian Young[5]; Yael Radzyner[2]
[1]*Tel-Aviv University, Israel*
[2]*Soreq Nuclear Research Center, Yavne, Israel*
[3]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
[4]*Los Alamos National Laboratory (LANL), Los Alamos, NM, USA*
[5]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
Corresponding Author: lschardong@tauex.tau.ac.il

The Israeli National Data Center is responsible for monitoring and characterising the seismicity of the Eastern Mediterranean region. The accuracy of seismic locations is mostly affected by the velocity model used, and no clear picture of the variations in seismic velocities in Israel has emerged in the recent years. We gathered a large dataset of seismic travel times recorded in Israel and nearby countries. After quality control and joint relocation of over 30,000 natural and man-made seismic events, we produced a revised dataset of more than 500,000 arrivals. From this dataset, we inverted Pg and Pn travel times for a crustal velocity model of the area using the FMTOMO tomographic inversion package. In order to do this, we put together a 3-D starting model that consists of an ensemble of 1-D velocity profiles for the various tectonic settings observed in the region. We present images extracted from this model, as well as corresponding synthetic resolution tests to assess the quality of our results. This high-resolution model is to be integrated into the Regional Seismic Travel Time model and procedure in order to enhance the CTBT's International Monitoring System capabilities in the Middle East.

Promotional text: We build a new model for crustal seismic velocities in Israel using a local travel-time dataset we put together. The new model is to be integrated into the Regional Seismic Travel Time model and procedure in order to enhance the CTBT's monitoring capabilities in the Middle East.

P1.2 The Solid Earth and Its Structure Abstracts of Poster Presentations

P1.2-041 – Lithospheric Structure of Africa and Surrounding Regions Revealed by Earthquake and Ambient Noise Surface Wave Tomography

Authors: Adebayo Ojo[1]; Weisen Shen[2]; Sidao Ni[3]; Li Zhao[4]; Jun Xie[3]; Honn Kao[1]
[1]*Geological Survey of Canada, Ottawa, ON, Canada*
[2]*State University of New York at Stony Brook, New York, USA*
[3]*Chinese Academy of Sciences, Beijing, China*
[4]*Peking University, Beijing, China*
Corresponding Author: ojo.adebayo.oluwaseun@gmail.com

To advance the understanding of the tectonic processes shaping the African continent, we construct the first continental-scale shear-wave velocity (Vs) model of the lithosphere from the joint analysis of ambient seismic noise and earthquake data recorded by ~1529 seismic stations in and around Africa. We apply the widely used ambient noise cross-correlation and earthquake two-station methods to retrieve the Rayleigh-wave group and phase velocity dispersions which are jointly inverted for a new three-dimensional Vs model. The inclusion of short-period dispersion data from ambient noise allows us to obtain a more accurate model than previous global and continental-scale studies, revealing lithospheric structures that correlate well with known tectonic features. In sparsely instrumented regions of north-central Africa, our model provides seismic evidence for the existence of cratonic remnants beneath thick sediments within the Sahara Metacraton and reveals unique mantle upwelling beneath hotspots suggesting that they may

be fed by unconnected plumes. The estimated crustal thickness varies among and within tectonic provinces and shows no clear evidence for the secular variation in crustal genesis. Our new model has the potential to serve as a reference velocity model for Africa and is useful for practical applications including monitoring of the Comprehensive Nuclear-Test-Ban Treaty.
Promotional text: We present the first 3D model of the lithosphere beneath Africa and surrounding regions from joint analysis of ambient seismic noise and earthquake data. New constraints on structures in sparsely instrumented regions of North Africa makes it valuable for monitoring of the CTBT.

P1.2-053 – Towards Building a Ground Motion Data Base to Improve the Seismic Hazard Assessment in Bolivia (Plurinational State of)

Author: Gonzalo Antonio Fernandez[1]
Co-authors: Mayra Nieto Canaviri[1]; Walter Arce[1]
[1]*Observatorio San Calixto, La Paz, Bolivia*
Corresponding Author: director@osc.org.bo

Seismic hazard assessment for any region in the world has become a very serious and difficult task for seismologists, civil engineers and decision makers. Probabilistic hazard studies are conducted at the Observatorio San Calixto (PSHBO-2019) to estimate the maximum peak ground acceleration integrating all available variables, however no strong motion time-series (waveform) were applied due to the limited equipment installed in the country. To solve this issue, since 2016 we started to compile and to convert the velocity frames from our IMS stations (LPAZ and SIV) and temporal seismic network installed in the country to have acceleration and displacement traces. These waveforms were pre and post treated to obtain the pseudo acceleration, velocity and displacement spectrum and they were tested with regional ground motion prediction equations in order to validate them for local use. A set of 80 earthquakes are presented that will contribute to the improvement of PSHBO-2019.
Promotional text: The new database proposed will help to improve and to categorize the different zones with their own seismic design spectrum to improve the seismic hazard in Bolivia.

P1.2-060 – Seismic Hazard Estimates for State of Uttarakhand Himalaya in Terms of Peak Ground Acceleration (PGA)

Author: Daya Shanker[1]
Co-author: Shubham[1]
[1]*Indian Institute of Technology, Roorkee, India*
Corresponding Author: d.shanker@eq.iitr.ac.in

Probabilistic Seismic Hazard Assessment (PSHA) for the state of Uttarakhand (280-320 N and 770-810 E) has been investigated considering two Next Generation Attenuation (NGA) models. Results are presented in terms of PGA for various return periods for each district. Initially, based on seismicity and seismtectonic characteristics the whole region has been defined into four seimogenic zones (UKI, UK-II, UK-III and UK-IV). Seismic hazard computation is performed using CRISIS 2015. The study area has been divided into grid size of 0.2° x 0.2°. The input parameters are seismicity parameters and attenuation models. The estimated seismicity parameters and (NGA) models have been used to produced seismic hazard in terms of PGA for 20%, 10% and 2% probability of exceedance in 50 years which are equivalent to return periods of 225, 475 and 2475 years respectively. The hazard Contour maps have been produced for mean PGA for 2%, 10% and 20% probability of exceedance in 50 years as well as Uniform hazard spectra (U.S. at various sites for return periods of 225, 475 and 2475 years have been plotted and the rate of occurrence of earthquakes and PGA are compared in each source zone).
Promotional text: Earthquake disasters lead to the loss of life, property damage and other socioeconomic disruption. These risks can be reduced by understanding complexities of the earth, dynamic and static properties; analyses and scientific interpretation of monitoring data and its application.

P1.2-094 – National Network Data Contributions to Seismic Studies in the Kingdom of Saudi Arabia

Author: Rengin Gok[1]
Co-authors: Zaam Otaibi[2]; Yahya Tarabulsi[2]; Ahmed Housny[2]; Andrea Chiang[1]; Michael Pasyanos[1]
[1]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
[2]*Saudi Geological Survey, Jeddah, Saudia Arabia*
Corresponding Author: gok1@llnl.gov

Increased urban development, occasional volcanic swarms, and large earthquakes surrounding the Kingdom of Saudi Arabia (KSA) have contributed to a renewed interest in understanding seismic hazard and risk within the Kingdom. In response, the KSA has expanded the national seismic network over the past several decades. Now, a sizable collection of local and regional data provides an opportunity to further develop KSA capabilities in seismology and seismic hazard assessment. The Lawrence Livermore National Laboratory (LLNL) and the National Center for Earthquakes and Volcanoes (NCEV) of the Saudi Geological Survey (SGS) started collaborating in 2016, with long-term goals of reducing seismic hazard and risk. We began by using time-domain full waveform moment tensor inversion and coda-envelope derived amplitude measurements to solve for earthquake source mechanism, moment magnitudes, and their source-type. We compare the moment magnitudes calculated from the two methods and publicly available earthquake catalogs and discuss the implications of the obtained source parameters. This study supports NCEV operational needs while obtaining stable and robust solutions that give quantitative information about the seismicity needed to better understand potential seismic hazards. A parallel collaborative study is focused on improving attenuation models of lithosphere for a broad frequency band using multiple-phase inversion.

P1.2-120 – Updates to the Regional Seismic Travel Time (RSTT) Tomography Model: Tomography and Path-Dependent Uncertainty

Author: Michael L. Begnaud[1]
Co-authors: Stephen Myers[2]; Brian Young[3]
[1]*Los Alamos National Laboratory (LANL), Los Alamos, NM, USA*
[2]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
[3]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
Corresponding Author: mbegnaud@lanl.gov

A function of global monitoring of nuclear explosions is the development of Earth models for predicting seismic travel times for more accurate calculation of event locations. Most monitoring agencies rely on fast, distance-dependent one-dimensional (1D) Earth models to calculate seismic event locations quickly and in near real-time. RSTT (Regional Seismic Travel Time) is a seismic velocity model and computer software package that captures the major effects of three-dimensional crust and upper mantle structure on regional seismic travel times, while still allowing for fast prediction speed (milliseconds). We describe published updates to the RSTT model (pdu202001Du, https://www.sandia.gov/rstt) using a refined data set of regional phases (i.e., Pn, Pg, Sn, Lg). We improve on the former distance-dependent uncertainty parameterization for RSTT using a random effects model to estimate slowness uncertainty as a mean squared error for each model parameter. The random effects model separates the error between observed slowness and model predicted slowness into bias and random components. Validation of the updated RSTT model demonstrates significant reduction in median epicenter mislocation along with more appropriate error ellipses, compared to the iasp91 1D model as well as to the current station correction approach used at the Comprehensive Nuclear-Test-Ban Treaty Organization International Data Centre.

Promotional text: The inclusion of new data for RSTT from prior Workshops addresses Goals 3-5, while the update of RSTT in general applies to Goals 1 and 5 for identifying opportunities to improve nuclear test monitoring and to promote wider civil and scientific applications.

P1.2-155 – International Data Centre Magnitudes and Their Relation to International Seismological Center Magnitudes Using Data for Ethiopia and Eritrea Regions

Author: Khalda Yassin Ibrahim Ali[1]
[1]*Seismological Research Institute, Khartoum, Sudan*
Corresponding Author: khalda7@hotmail.com

Various type of magnitude scales are recognized for estimating the earthquakes size. Magnitude is one of the significant factors for a unified earthquakes catalog which is needed for seismic hazard assessment and disaster management. The variation in magnitude value from seismological agency to other stimulated the researchers to study the regression relationship between the magnitudes. The study area is located between latitudes 4°-16° and Longitudes 36°-42° in the east Africa region. A selected number of events which has magnitudes ranges from 3 to 5.6 for the period between 2000 and 2020 were used to create the regression relations. In this research the standard least-square regression (SR) and orthogonal regression (OR) were derived to assess the relation between the international data center (IDC) magnitudes in addition to the international data center (ISC) magnitudes based on body wave magnitude (mb), surface wave magnitude (MS) and local magnitudes, these regressions were adopted to choose the best regression model. Finally, the conversion equations between magnitudes were constructed and determined for wide range about twenty years.

Promotional text: The objective of this study is to derive relation between IDC magnitudes to help when it becomes difficult to read any type of magnitude and to find relations between IDC and ISC magnitudes to solve any problem in magnitudes for the same events in case of missing or unclear data.

P1.2-171 – The Use of Seismological, Geodetic and Infrasound Techniques for Novel Integrated Monitoring Scheme in Nigeria

Author: Umar Afegbua Kadiri[1]
Co-authors: Tahir Yakubu[2]; Monday Isogun[2]
[1]*Ministry of Science and Technology, Abuja, Nigeria*
[2]*Centre for Geodesy and Geodynamics, Toro, Nigeria*
Corresponding Author: umakad@yahoo.com

Nigeria lies within the West African sub-region and the country is believed to be aseismic in nature. Despite this view by prominent geoscientists, the country has witnessed both historical and instrumental earthquakes since 1933. The recent recorded chains of events with moment magnitudes ranging from 3.0 to 3.4 in Nigeria, were located in Kaduna state and Abuja. Reasons which include shallow faults reactivation by hydraulic fracturing, anthropogenic causes, etc., have been adduced to the recurrent earth tremors in Nigeria. As the events are of small to medium magnitudes, their vibrations felt in different parts of the country were not recorded by the scanty existing seismic stations. This paper therefore, presents a novel integrated approach towards understanding Nigeria's seismicity, and enhanced monitoring of seismic hazard through improved recording capability of earthquakes. It outlines a detailed scheme on densification of seismographs collocated with GPS, and deployment of the advanced Infrasound equipment to strategic areas where earth vibrations are frequently observed in Nigeria but not recorded by seismic equipment, etc. The realization of the monitoring scheme would not only assist Nigeria in seismic risk mitigation and holistic planning, but will promote collaboration with the CTBTO and other key partners.

Promotional text: This study supports the wider civil and scientific applications of CTBT techniques by adopting one of its tools for verification (Infrasound), in addressing seismic hazard challenges in Nigeria and boosting awareness of the powerful technology to broader scientific community.

P1.2-188 – Analysis of Foreshock Sequences in the Iranian Plateau

Authors: Amir Mansour Farahbod[1]; Mania Sabouri[2]
[1]*Geological Survey of Canada, Ottawa, ON, Canada*
[2]*Engineering Seismology, IIEES, Montreal, Canada*
Corresponding Author: mania7@gmail.com

We analyze foreshock activity in the Iranian plateau by investigating the occurrence patterns for isolated M ≥5.5 earthquakes from 1968 to 2018. Among the 165 mainshocks with M ≥5.5 (after excluding 12 aftershocks, 6 swarms and 9 doublets), 18 percent are preceded by at least one foreshock within 30 days and 20 km. However, the number of events in each foreshock sequence is significantly higher in the last ten years of the catalog. This difference is partly explained by the rapid expansion of the Iranian national seismographic network in the recent years. Based on our analysis, the completeness magnitude of the catalog is declined over years and reached to 3.4 (2008-2018) from 5.1 (1968-1998). Foreshock occurrence appears correlated with mainshock faulting type and depth; however, it is not correlated with mainshock magnitude. These results suggest that foreshock occurrence is largely controlled by the regional tectonic stress field and fault zone properties. In special cases, foreshock activity is considered as one of the most promising precursory changes for the main shock prediction in the short term; however, foreshock properties are not reliably predictive of the magnitude of the eventual mainshock.

Promotional text: In this study, we investigate foreshock activity of large earthquakes in the Iranian plateau by using available catalogs. Also, we provide a summary of expansion and modernization of the Iranian national seismic network over 50 years.

P1.2-201 – Development of Local Magnitude Scale and Determination of Station Magnitude Corrections for Northern Thailand

Author: Tanongsak Taothong[1]
[1]*Thai Meteorological Department, Bangkok, Thailand*
Corresponding Author: tanongsak.tmd@gmail.com

In this research, a local earthquake magnitude formula (ML and MLv) was developed for measuring earthquake magnitude in northern Thailand and determined station magnitude corrections. By using data from 31 seismic stations of the Earthquake Observation Division, the Thai Meteorological Department and CTBTO Chiang Mai seismic station, analyzed 148 earthquake events from 2009 to 2019 to find the formula. The magnitude ML was defined as ML = log A + 0.6682 log(R/100) + 0.0026(R-100)+ 3 and the magnitude MLv was defined as MLv = log A + 0.6002 log (R/100) + 0.0030(R-100) + 3, for hypocentral distance 25 to 500 km and depth below 60 km. The results comparing Richter's local magnitude equation (1935) and the equation obtained from the study, found that the attenuation of earthquake magnitude in northern Thailand and southern California is quite similar. And the station magnitude corrections were between −1.1752 to 0.5393 magnitude.

Promotional text: Development of local magnitude scale and Determination of Station Magnitude Corrections for northern Thailand by Using data from Earthquake Observation Division, Thai Meteorological Department and CTBTO Chiang Mai seismic station.

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

P1.2-227 – Statistical Assessment of Seismicity Level of the Central Part of the Baikal Rift Zone

Authors: Larisa Tcydypova[1]; Tsyren Tubanov[1]; Darima Sanzhieva[1]; Evgenii German[1]; Petr Predein[1]
[1]*Geological Institute of the Siberian Branch of the Russian Academy of Sciences (GIN SB RAS), Russian Federation*
Corresponding Author: laramgu@yandex.ru

The seismicity change in time in the seismically active region around the central part of the Baikal rift zone (BRZ), the South-East of Russia, was investigated using the statistical estimate of the seismicity level (SESL'09) procedure [Saltykov, 2011]. The method is based on calculating the statistical distribution function of the decimal logarithm of the total seismic energy within a given spatial object in a certain time interval. Epicenter data taken from the International Seismological Centre [http://www.isc.ac.uk/iscbulletin/search/catalogue] and from the local catalogue from 1962 to 2019, which includes over 3.5 thousand earthquakes with an energy class equal to or higher than 8.5, were analyzed. This concept enables us to formed and defined "seismic background" for considered region. And allows us to conduct the further assessment and comparison with the seismic regimes of the other areas. The work has supported by the Ministry of science and higher education of the Russian Federation (within the framework of state task No. 075-01304-20 and the research project IX.136.1, state number AAAA-A16-116121550016-3) and using data obtained at the unique scientific installation "Seismic and Infrasound monitoring complex of the Arctic cryolithozone and continuous seismic monitoring complex of the Russian Federation, neighboring territories and the world".

Promotional text: Qualitative seismicity assessment in the central part of the Baikal Rift Zone by using the statistical estimate of the seismicity level procedure gives important information about background seismicity for the region and allows to study variations in seismicity levels over time.

P1.2-254 – Attenuation of Seismic Waves in the Northern Appalachians of Southeastern Canada

Authors: Amir Mansour Farahbod[1]; John Cassidy[1]
[1]*Geological Survey of Canada, Ottawa, ON, Canada*
Corresponding Author: amir.m.farahbod@gmail.com

We investigate seismic attenuation characteristics of the Canadian portion of the northern Appalachians. Coda Q is determined using 389 earthquakes (1.8 ≤ M ≤ 3.9) recorded on four stations of the Canadian National Seismic Network (CNSN) in New Brunswick from 1985 to 2020. For comparison, we divide the study area into northern and southern portions, each with two seismic stations and 162 and 227 events, respectively. At lapse times of 12 to 60 seconds, coda Q at 1 Hz (Q0) at the two seismic stations in the region of northern New Brunswick that is closer to the seismically active Charlevoix seismic zone (including a M7 event in 1663) is 82 ± 5 on average. In contrast, the two stations in southern New Brunswick have an average Q0 of 114 ± 3. The lower Q0 value in the north in comparison with the southern part of the region is in agreement with Jin and Aki's (1988) finding that Q0 is lower in the vicinity of large earthquakes. Ongoing mapping of coda Q in the area using the CNSN stations is planned in order to contribute to the ongoing development of more accurate seismic hazard models.

Promotional text: Our presentation provides an overall knowledge about coda Q in a region in southeastern Canada which is one of the most useful parameters for the study of earth structure and seismic hazard assessments.

P1.2-272 – Probabilistic Seismic Hazard Map for Bolivia (PSHBO)

Authors: Gonzalo Antonio Fernandez[1]; Mayra Nieto Canaviri[1]; Teddy Griffiths[1]; Walter Arce[1]; Marcelo Assumpcao[2]; François Schindele[3]; Stephanie Godey[3]; Nicolas Brachet[3]
[1]*Observatorio San Calixto, La Paz, Bolivia*
[2]*University of Sao Paulo, Brazil*
[3]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: director@osc.org.bo

On this research we present a probabilistic seismic hazard map for Bolivia (PSHBO-2019), this is the first map that integrated all variables available within the geo hazard for our country. We propose 13 seismic zones based on epicentral distribution, stresses and geology context, we applied the well know method for hazards assessment integration to all variables to have the maximum probable acceleration for each zone. Our results include a return period of 475 and 2475 years with five structural periods that let us to build the uniform hazard spectrum for our country. The crustal earthquakes located at along the Eastern Cordillera, Inter Andes and part of the Sub Andes (known as Bolivian Boomerang) present peak ground accelerations up to 24% of gravity, for the subduction earthquakes show almost 34% of gravity those are located at Western Cordillera, for Altiplano the peak ground accelerations reach up to 16%, for Chaco and Beni plains accelerations of 4% of gravity.
Promotional text: The probabilistic seismic hazard map for Bolivia (PSHBO-2019), this is the first map that integrated all variables available within the geo hazard for our country, using technologies the International Monitoring System.

P1.2-325 – The EOS's Broadband Seismic Network in Myanmar: Installation, Site Classification, Local Seismicity Reports and Velocity Structure Studies

Author: Phyo Maung Maung[1]
Co-authors: Shengji Wei[1]; Dannie Hidayat[1]; Kyaw Moe Oo[2]; Huang Bor-Shouh[3]
[1]*Nanyang Technological University, Earth Observatory of Singapore, Singapore*
[2]*Department of Meteorology and Hydrology (DMH), Ministry of Transport and Communication, Myanmar*
[3]*Institute of Earth Sciences, National Taiwan Ocean University, Taiwan*
Corresponding Author: uphyomgmg@gmail.com

To study the earthquakes and better understand the tectonics in Myanmar, Earth Observatory of Singapore (EOS) has been collaborating with local seismic monitoring authority to install (30) broadband seismic stations. With the broadband collected data, we have used them to study the site classification, earthquakes relocation and constrain the velocity structure. We defined our EOS's broadband seismic stations site classes by using the horizontal to vertical spectral ratio (HVSR) method from ambient seismic noise. We clearly identified some of our stations on the rock site such as EW01, M024, EW07, M027 which have resonance frequency larger than 5.0 Hz. The resonance frequency less than 1.6 Hz are defined as soft soil class such as EW05, M008, M012, M022. This kind of classification is based on the National Earthquake Hazards Reduction Program (NEHRP) site classes. From the initial automatic location that we have selected and relocated ~1000 earthquakes which we found that all these local earthquakes well define the Indian slab beneath Myanmar region. Moreover, use selected teleseismic events located between 30 to 90 degree distance to image the Moho beneath our seismic stations using P-receiver functions (PRFs) and H-K stacking technique to get crustal thickness and Vp/Vs ratio.

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Promotional text: Myanmar, Earthquakes relocation, Crustal thickness (Moho), Broadband Seismic Network.

P1.2-341 – Analysis, Processing and Interpretation of the Gravity Data Between Latitudes 15N-17N (Sudan)

Authors: Naila Mohamed Osman Babiker[1]; Abdalla Gumaa[2]
[1]*National Center for Research, Khartoum, Sudan*
[2]*University of Khartoum, Sudan*
Corresponding Author: nailaosman76@gmail.com

A gravity analysis and Interpretation are carried out using data collected by Sun-Oil Company in the area west of Khartoum between latitudes 15°-17° N and longitude 30°-33° E. The data released in a Bouguer anomaly map at scale of 1:500,000 and a contour interval of 5 mgal. The target is to analyze and interpret the gravity data in terms of surface and subsurface geology. The qualitative interpretation includes the construction of second vertical derivative map, analytical upward, downward continuation and separation of residual and regional anomalies. The operation of the second vertical derivative and analytical continuation is thought to be as a filtering operations based on the linear filter theory. Five models are used to construct a depth to the basement map. Geological sections are drawn along five profiles passing through boreholes of Elmagad, Abu Hashim and JebelAulia. The result revealed that the negative anomalies are associated with the existence of the Cretaceous Nubian Sandstone sediments as in the cases of BagBag, Hummar and AbuDulu basins with maximum depth of 3000, 1000, and 1900 meters respectively. These basins are considered as parts of the Blue Nile Rift Basin that has been subjected to tectonic movements which affect the central Sudan.
Promotional text: New approach in this type of study can be achieved through cooperation and exchange of knowledge especially the release of new software through participation in such conferences.

P1.2-357 – 3-D Tomography of the Crustal Structure of the Central Part of Madagascar

Author: Ramarolahy Rina Andrianasolo[1]
[1]*Institute and Observatory of Geophysics of Antananarivo (IOGA), Madagascar*
Corresponding Author: rinaranamana@gmail.com

Madagascar has never had a big earthquake until now. The biggest earthquake had a magnitude of 7 Richter, and not on land but in the ocean. The highest magnitude on land was below 6 Richter. The central part of the big island is the most active seismically. It can be clustered into three zones. Two of them are a Cenozoic volcanic area, which are Itasy and Ankaratra, from the north-west and the south respectively. The last seismically active zone is Alaotra, at the north-east part, and at the Alaotra-Ankay rift composed by normal faults. Many scientific articles say the volcanoes in the central part are already extinct and some say there have been recent eruptions, which means they are dormant volcanoes. The seismic map reveals that the epicenters tend to line up from the volcanic area of Ankaratra to Itasy and expand till Bongolava. A 3D tomography of this zone was done, with the permanent stations including the CTBTO station, to determine and study the structure of the crust which is thinner than the coastal areas.
Promotional text: As the CTBTO promotes the third party countries scientists, I would like and very motivated to present our work from Madagascar. No 3D study of the crustal structure of the big island has done yet, attending the SnT21 would be an opportunity to share and get experiences.

P1.2-367 – About Regularities of Seismicity of Western and Central Uzbekistan

Author: Makhira Usmanova[1]
[1]*The Institute of Seismology of the Academy of Sciences of Uzbekistan, Tashkent, Uzbekistan*
Corresponding Author: m.usmanova@mail.ru

Space-temporal distribution of seismic activities in Western and Central Uzbekistan is considered. Four groups of strong earthquakes in the regions were analyzed. The pattern of redistribution of the accumulated tectonic energy in the form of seismic activity in the regions is revealed. In a westeast direction, an increase in the depth of earthquakes is noted. Deviations from the regularity of grouping of strong earthquakes in the seismic regime of the region is found. Periods of seismic activity of the Western Tien-Shan in the Asian part of the Mediterranean-Asian seismic belt showed their regional and planetary synchronization. Late periods of seismic activity of Western Tien-Shan had been explained by low level magnitude M=5.3 of main shocks in the group. Study of the seismic regime of the region where the triple Gazli earthquakes of 1976 and 1984 occurred, M=7.0-7.3 were probably preceded by triggers. Natural triggers: active processes of cracking (large cracks up to 100 km in length) observed in 1965; small mud volcanoes "griffons"; the absence of significant earthquakes in the Gazli region more than 40 years. Technogenic triggers: a permanent 40-year operation of "Gazly" gas fields: two nuclear explosions of 1966, 1968, which occurred near the Gazly earthquakes of 1976, 1984 that have a tectonic nature.

Promotional text: In research about influence, nuclear explosions to seismic regime on Western and Central Uzbekistan noted.

P1.2-368 – Upper Crustal Structure at the KTB Drilling Site from Ambient Noise Tomography

Author: Ehsan Qorbani[1]
Co-authors: Irene Bianchi[2]; Petr Kolínsky[3]; Dimitri Zigone[4]; Götz Bokelmann[3]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*National Institute of Geophysics and Volcanology (INGV), Rome, Italy*
[3]*University of Vienna, Vienna, Austria*
[4]*Institut de Physique du Globe de Strasbourg, Université de Strasbourg, France*
Corresponding Author: eqorbani@gmail.com

In this study, we show results from ambient noise tomography at the KTB drilling site, Germany. The Continental Deep Drilling Project, or 'Kontinentales Tiefbohrprogramm der Bundesrepublik Deutschland' (KTB) is at the northwestern edge of the Bohemian Massif and is located on the Variscan belt of Europe. During the KTB project crustal rocks have been drilled down to 9 km depth and several active seismic studies have been performed in the surrounding. The KTB area therefore presents an ideal test area for testing and verifying the potential resolution of passive seismic techniques. The aim of this study is to present a new shear-wave velocity model of the area while comparing the results to the previous velocity models. We use a unique data set composed of two years of continuous data recorded at nine 3-component temporary stations installed from July 2012 to July 2014 located on top and vicinity of the drilling site. Moreover, we included a number of permanent stations in the region in order to improve the path coverage and density. We present here a new velocity model of the upper crust of the area, which shows velocity variations at short scales that correlate well with geology in the region.

Promotional text: We use seismic ambient noise data recorded at seismic stations to image the upper crustal structure around the KTB drilling site in Germany. The results are well matched with the surface geology and improve our understanding of the complex structure of the shallow crust.

P1.2-369 – Investigating Seismic Radial Anisotropy Beneath the Zagros Belt

Authors: Ramin Movaghari[1]; Gholam Javan Doloei[1]
[1]*International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran*
Corresponding Author: ramin.movaghari@gmail.com

In this research, the difference between the velocity of Rayleigh and Love waves is used to determine radial anisotropy beneath the Zagros belt. The continuous ambient noise data are processed to image 2D tomographic dispersion maps from the period of 8 to 50 s. Then, a quasi-3D shear wave velocity and radial anisotropy model are calculated by joint inversion of the Rayleigh and Love local phase velocity dispersion curves using MCMC method. Our results imply the presence of intense radial anisotropy due to the dense minerals in the crust and uppermost mantle of the Zagros zone. Radial anisotropy changes from positive values in the crust to negative values in the upper mantle which may be evidence for the decoupling of the crust from the upper mantle beneath the Zagros.
Promotional text: Shear wave velocity and radial anisotropy model of the Iran plateau was determined using Bayesian Markov chain Monte Carlo inversions. Radial anisotropy patterns suggest ductile shear zones in the middle to the lower crust beneath the Zagros.

P1.2-503 – Occurrence and Extent of Earth Fissures: Preliminary Findings from Chikwawa District, Southern Malawi

Author: Patrick Rafiki N. Chindandali[1]
[1]*Geological Survey of Malawi, Malawi*
Corresponding Author: rafikiwanga@gmail.com

Although earth fissures have occurred in some parts of the country, they have not been well-documented or studied in detail. Recent field investigation into the formation and extent of earth fissures in Chikwawa District, reveal their formation due to erosion as well as tensional cracks within the affected area as a result of groundwater withdrawal from the alluvial sediments. Several sinkholes and linear fissures trending N-S and E-W, connected by horizontal conduits characterized by mud deposition and mud flow, cut through the village thereby weakening and cracking houses. Minor fissures connect orthogonally to major fissures without clear offsets. The water flow through the conduits influenced the formation of sinkholes and conduits by weakening their structural strength which caused top soil to collapse into existing voids, creating or widening the sinkholes and exposing the conduits. We used geological, airborne geophysical as well as seismic ambient noise to delineate structures and determine depth-to-bedrock. Additionally, data from local as well as international seismological monitoring networks indicate no occurrence of an earthquake in the vicinity to attribute such activity to tectonic movement or faulting.
Promotional text: Fissures, Sinkholes, Alluvium, Tectonics, Faulting.

P1.2-538 – United Arab Emirates Strong Motion Network

Author: Mohamed Al Afeefi[1]
Co-author: Ali Megahed[1]
[1]*National Center of Meteorology, Abu Dhabi, United Arab Emirates*
Corresponding Author: malafeefi@ncms.ae

UAE strong motion network consists of 62 stations distributed all over the country to construct UAE-Ground GSM "ShakeMaps" for existing urban areas and areas under strategic development. Additionally, structural design parameters will become available for verification and calibration of the seismic design code. Forty stations are equipped with shallow borehole EpiSensors and fourteen stations with surface EpiSensors installed on open ground or in small buildings and 7 stations equipped with TSA-100 and one station equipped with Titan. Stations use high dynamic range, IP aware, digitizer model Basalt, Trident or Quanterra,

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

for data acquisition. The network telemetry topology consists of wireless GPRS backbone with data service from multiple ISPs and some station transmit data via VSAT. A site characterization study at each site included geotechnical and geophysical analyses, microtremor testing, and soil dynamic investigations. The integral results provide estimation on the potential effects of local site conditions upon recorded ground motions. The primary operational objective is to provide input accelerations in real-time for the automatic calculation and distribution of reliable UAE-GSM "ShakeMap" immediately after a seismic event.

Promotional text: A description of the UAE Strong Motion Network as well as the various sensors that are used to provide a complete coverage of the seismic activity of the region.

P1.2-544 – Seismic and Aseismic Observations and Self-Similar Theory

Author: Mohamed Alwahedi[1]
[1]*National Center of Meteorology, Abu Dhabi, United Arab Emirates*
Corresponding Author: maalwahedi@ncms.ae

The postseismic slip that follows large earthquakes is typically a few tens of percent of the coseismic moment, while the postseismic slip following small earthquakes appears to be comparable to the moment. Here I estimate the postseismic slip following intermediate-magnitude earthquakes and find that it is intermediate between the two, about 40% of the coseismic moment. The variation in postseismic slip with moment suggests that earthquakes may not be self-similar: that the properties of earthquakes or the regions that surround earthquakes vary systematically with earthquake size. If this is true, it would reveal a global fact related the physical processes of earthquakes.

Promotional text: This study is important for a better understanding of earthquake physics, which helps us in improving Earth models. If moderate earthquakes could produce large postseismic offsets which is related to aftershocks, then those postseismic values would be vital for hazard assessment.

P1.2-545 – Modern Seismological Network of Nepal

Authors: Lok Bijaya Adhikari[1]; Laurent Bollinger[2]; Monika Jha[1]; Bharat Koirala[1]; Mukunda Bhattarai[3]; Chintan Timsina[1]; Corentin Quedec[2]
[1]*National Seismological Centre, Department of Mines and Geology, Kathmandu, Nepal*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[3]*National Earthquake Monitoring and Research Center, Kathmandu, Nepal*
Corresponding Author: lbadhikari@hotmail.com

Nepal is exposed to intense seismic activity, including devastating earthquakes. The National Earthquake Monitoring and Research Centre (NEMRC) was established under the Department of Mines and Geology (DMG) to monitor those earthquakes. It also alerts the Nepalese authorities and population about the location and magnitude of the felt earthquakes to support rescue and relief operations at the earliest. The seismological network was deployed in collaboration with the Department of Analyse, Surveillance, Environment (DASE), France, and extended to a national network covering the whole territory since 1994. 21 short period stations were tele-operated at two seismic centres, a network updated to digital between 2014 and 2016. NEMRC provides some seismic bulletins to international institutes and became the NDC of Nepal for CTBTO. The Gorkha earthquake (Mw 7.9) happened on 2015 April 25 under the network's central part. The number of stations were then increased with several international organizations (including Chinese and Japanese institutes). It now reaches a total of 41 broadband and short period instruments. These stations, exposed to low seismic noise levels, recorded more than 100,000 earthquakes, including more than 50,000 events following the Gorkha earthquake. The modern network allows improving the quality of the catalogue useful for seismological research.

Promotional text: The seismological network of Nepal has become denser following the Gorkha earthquake of 25 April 2015.

Now the network with broadband and short-period seismometers allows the better location and seismological research.

P1.2-631 – Identifying Suspect Instrument Intervals Using Midnight Noise Time Histories

Author: William Scott Phillips[1]
Co-author: Richard J. Stead[1]
[1]*Los Alamos National Laboratory (LANL), Los Alamos, NM, USA*
Corresponding Author: wsp@lanl.gov

Instrument response issues are common in seismology, and they can hinder research. We use large data sets to develop models that will predict high-frequency seismic amplitudes, which requires extensive quality control. To identify response and station health issues, we have collected time histories of noise measurements near (but not restricted to) midnight to eliminate diurnal variations, and have manually determined time intervals that appear inconsistent with background behavior. We assign descriptive labels, but do not attempt to diagnose causes. We currently use results to discard data. To date, we have examined 39,260 channels from 11,105 stations, heavily weighted toward Incorporated Research Institutions for Seismology (IRIS) holdings, at bands between 1 and 8 Hz, finding 24,733 anomalous time intervals that represent 13% of the total inspected time range. The majority (90%) of these intervals are constant offset shifts, often bounded by known instrument changes, likely resulting from poor response documentation at one of many stages between the field and publication. We hope these results can be of use to our colleagues, and encourage community efforts to diagnose anomalous behavior, and fix poor responses. We also hope these results will support automation efforts, including application of supervised learning techniques.
Promotional text: We demonstrate methods to improve nuclear monitoring and verification through studying noise time histories that can be used to identify issues with seismic instrumentation and calibration.

P1.2-659 – How Reliable Are Moment Tensors of Small Earthquakes?

Authors: Lucia Fojtikova[1]; Jiri Zahradnik[2]; Kristian Csicsay[3]
[1]*Earth Science Institute, Slovak Academy of Sciences, Bratislava, Slovakia*
[2]*Charles University in Prague, Czech Republic*
[3]*Earth Science Institute of the Slovak Academy of Sciences, Bratislava, Slovakia*
Corresponding Author: geoflufo@savba.sk

Calculation of moment tensors of weak seismic events is challenging. Quite often we face a lack of stations and inaccurate velocity models. However information on moment tensors is important for understanding origin of the events (explosions, natural and induced earthquakes) and seismotectonics regime of the area. We re-analyzed two methods of retrieving moment tensors: (i) Inversion of amplitudes of P- and S-waves, and (ii) inversion of three-component full waveforms, complemented by first-motion polarities. The methods utilize different types of waves, different frequency bands, and different methods to calculate Green's functions. We compare and discuss the methods in terms of reliability, efficiency and accuracy. The discussion is performed on examples of two weak earthquakes from Slovakian-Ukrainian border which appeared in April 2020, with local magnitudes 3.2 and 2.3.
Promotional text: To increase reliability of moment tensors of small seismic events, we analyze inversion of P- and S-wave amplitudes and three-component full waveforms. As example, we discuss two earthquakes from Slovakian-Ukrainian border from April 2020, with local magnitudes 3.2 and 2.3.

T1.3 The Oceans and Their Properties

Highlights

Technical Developments

P1.3-270 presented the development of a new concept in modular hydroacoustic components with the advantage of making it possible to replace failing components in situ. The presentation focused on the modular design and latch mechanism that prevents excessive mechanical load of wet-mate connectors during deployment of a hydroacoustic modular node from a ship and allows cables resting on the sea floor to be detached from the modular nodes composing the triplet after deployment. The modular design allows deployment of triplets in a continuous string, similar to current practices, with the additional advantage of enabling the repair of individual components using remotely operated vehicles deployed from a ship. A prototype latch mechanism has been designed and fabricated, and basic functionality tests have been performed. Additional tests are planned to validate mechanical strength and optimize the design.

O1.3-705 provided an update on SMART subsea cables for monitoring the ocean and earth on a planetary scale. The cables have a sensor component that can be opportunistically incorporated into commercial telecommunications cables and equipped with low-cost sensors. SMART cables are proposed as a means of providing observations related to climate change, ocean currents, sea level rise, and earthquake and tsunami early warning. The main ocean parameters to be measured are bottom pressure and temperature, and seismic acceleration.

P1.3-284 described a self-consistent estimate of HA3 (Chile) hydrophone locations using scientific airgun data from the Crustal Examination from Valdivia to Illapel to Characterize Huge Earthquakes (CEVICHE) project in Chile. The small corrections to the hydrophone locations were implemented in the independent back azimuth estimator DTK-GPMCC provided by the French NDC at CEA. Knowing the accurate deployment position of each hydrophone in the triplet of an IMS hydrophone station is essential to obtaining the accurate location of an event by back azimuth estimation.

Signal Analysis and Event Association

P1.3-402 presented the analysis of years of data processed using the DTK-PMCC algorithm detector. Global association of detections is performed to build automatic events. The analysis makes it possible to display the spatial locations of active seismic areas, detections and associations of ice-quake events, superimposed with airgun surveys and whale vocalizations. Locations of low-amplitude events were obtained by the accurate back azimuth estimates, simple blockage maps and back azimuth crossings for two and four hydrophone stations. These event locations compare well with independent event catalogues and demonstrate the impressive monitoring capability of the relatively few IMS hydrophone stations.

O1.3-262 described the determination of long term and seasonal trends in deep ocean acoustic noise measured at IMS hydroacoustic stations. Data from hydrophone stations HA1 (Australia), HA10 (USA) and HA11 (USA) were analysed for periods of 12 years or more. In particular, changes in the noise level during the COVID-19 pandemic in 2020 were analysed. Most results indicate a decrease in noise level in the first half of 2020 and a return to the usual noise level in the second half of 2020.

O1.3-489 addressed hydroacoustic data analysis in relation to global climate change studies using data from IMS hydrophones, together with data from Argo floats and acoustic thermometry of ocean climate. Repeated natural earthquakes were used as sound sources. Travel time changes of acoustic waves (T waves) originating near such earthquakes were analysed from 2002 until 2017. Measurements of 2600 repeated earthquakes were obtained using the hydrophones of HA8 (UK) and provided high temporal resolution to infer basin-scale average ocean temperature changes. Data sets from the hydrophones and seismic sensors exhibit a high degree of consistency.

The archived ambient noise recordings made at the hydroacoustic stations of the IMS provide a unique platform for the use of a fully passive acoustic approach for ocean remote sensing. O1.3-648 presented a proof of concept of passive acoustic thermometry to estimate deep ocean temperature variations and internal tides using coherent processing of low-frequency ambient noise.

P1.3-273 discussed the hypothesis that occasional short duration broadband signals from IMS hydrophone stations HA1 (Australia), HA3 (Chile) and HA4 (France) are the low-frequency portion of an impulsive signal referred to as right whale "gunshots". Right whales are endangered species, and recordings of their vocalizations are relatively rare in comparison with vocalizations of other whales.

Volcanic eruptions at Kadovar Island, Papua New Guinea, resumed in January 2018 after a quiet period of three centuries. P1.3-291 presented hydrophone recordings by IMS hydrophone station HA11 (USA) that were associated with these eruptions. The discrimination from other sources was performed by time–frequency and cross-correlation analysis of the signals. Signals were associated with eruptions near the shoreline. Long duration and small amplitude signals were associated with flank collapse.

P1.3-546 presented a study of several underwater explosions detonated close to the coast of Florida, USA, in September 2016 as part of shock tests of US Navy vessels and four impulsive-like events of unknown origin from the Kamchatka Peninsula in the Russian Federation. The standard processing algorithms Analyst Review System (ARS), Hydroacoustic Azimuth Review Tool (HART) and DTK-GPMCC used at the IDC were employed to estimate the signal back azimuth at HA10 (USA) for the Florida explosions and HA11 (USA) for the impulse-like events from Kamchatka. Primary arrivals were immediately followed by a secondary arrival that could be associated with reflections from seamounts and coastal regions. Back azimuth estimates of both primary and secondary arrivals from HART and DTK-GPMCC were in general consistent. Identification of reflected arrivals can potentially be incorporated in the IDC processing system to improve localization of in-ocean events by IMS hydrophone stations.

P1.3-331 suggested the possible detection of the loss of the cargo vessel *SS El Faro* by hydroacoustic station HA10 (USA) during Hurricane Joaquin in 2015. A recording of one impulsive signal in the ocean at HA10 was associated with this event, with origin time and location coinciding with independent information about the loss. The back azimuth estimate based on the PMCC technique is consistent with the presumed last location of the vessel.

Propagation Models and Validation

P1.3-095 focused on the application of high-performance computing for ocean modelling. Implementation of a code based on solving the frequency domain 3-D parabolic equation gained a factor of 20 in computation time and 100 for a 2-D finite difference time domain model. P1.3-425 used such capabilities to analyse recorded T waves from a 7.4 magnitude earthquake near the Kermadec Trench. DTK-GPMCC was applied to estimate the back azimuths of the T waves. Signal propagation computations used a model based on solving the 3-D parabolic equation. The back azimuth of the signals recorded at HA10 (USA) and HA11 (USA) deviates from expectations based

EXECUTIVE SUMMARY
AR CN EN FR RU SP

on geodesic propagation paths from the epicentre to the hydrophone stations, and these deviations are possibly caused by horizontally reflected and diffracted propagation paths. The results suggest that the location of the coupling point from seismic to ocean acoustic signals varies along the trench and differs significantly from the announced epicentre.

P1.3-490 discussed 3-D ocean acoustic signal propagation computations for a stratified ocean. An indirect boundary element model formulation that provides a more stable solution was evaluated against representative shallow water benchmark situations. P1.3-526 used the combined normal mode–parabolic equation method to carry out modelling of ocean acoustic signal propagation, claiming to be capable of calculating 3-D ocean acoustic signal propagation and signal arrival time at higher acoustic frequencies than models based solely on the parabolic equation. P1.3-408 emphasized the need for awareness of possible local and temporal changes in sound speed in the ocean with the potential to impact medium to high frequency acoustic propagation.

P1.3-494 evaluated whether signals from offshore seismic surveys with airgun array sources can be used to validate theoretical predictions of propagation models. An inverse problem approach was taken. The sound pulses from large airgun arrays generate signals that contain sufficient energy in the 5–60 Hz band to propagate ocean basin scales at ranges of hundreds to thousands of kilometres. A sample of recorded signals from seismic surveys obtained from historical IMS hydroacoustic data was exhaustively analysed through cepstral, spectral and time-based techniques to infer underwater propagation properties.

O1.3 The Oceans and Their Properties Abstracts of Oral Presentations

O1.3-262 – Investigation of Trends in Ocean Noise Determined from CTBTO Hydroacoustic Stations, Including During the 2020 COVID-19 Lockdown Period

Authors: Stephen Robinson[1]; Peter Harris[1]; Sei-Him Cheong[1]; Lian Wang[1]; Valerie Livina[1]
[1]*National Physical Laboratory (NPL), Teddington, United Kingdom*
Corresponding Author: stephen.robinson@npl.co.uk

This paper describes the determination of long term and seasonal trends in deep-ocean acoustic noise measured at the CTBTO hydroacoustic stations, and the investigation of the potential for changes in noise levels in 2020 during the COVID-19 pandemic. The analysis method uses a flexible model that incorporates terms that capture long-term trends in the data, seasonal variations and short-term serial correlations, together with associated uncertainties. The measured data originate from a number of the hydro-acoustic monitoring stations operated by the CTBTO and span up to a maximum of 17 years. The analysis here focuses on the data from Cape Leeuwin (Southern Ocean), Wake Island (Pacific Ocean), and Ascension Island (Atlantic Ocean). The trend analysis is applied to time series representing aggregated statistical levels for four frequency bands to obtain estimates for the change in sound pressure level with associated coverage intervals. The features of the data are described, including the differences observed in the seasonal variation and the long-term trends, with the latter often exhibiting negative gradients. An examination is provided of changes observed in the 2020 data compared to the expected values based on earlier years, with the discussion informed by data for anthropogenic sources of sound.
Promotional text: Trends from deep-ocean noise data are derived from CTBTO stations including assessment of "COVID quietening" in 2020. Influence of anthropogenic and global environmental (climatic) factors are described.

O1.3-489 – Seismic Ocean Thermometry Using CTBTO Hydrophone Data

Authors: Wenbo Wu[1]; Zhongwen Zhan[1]; Shirui Peng[1]; Zhichao Shen[1]; Jörn Callies[1]
[1]*California Institute of Technology, CA, USA*
Corresponding Author: wenbow@caltech.edu

As the major buffer of Earth's energy imbalance, the ocean plays a key role in regulating global climate and temperature changes. However, accurate estimation of global ocean temperature change remains a challenging sampling problem. To complement existing point measurements, we have developed a novel and low-cost method of using travel time changes of acoustic waves from repeating natural earthquakes to infer basin-scale average ocean temperature changes. In this study, we implement this method using the CTBTO hydrophones H08 near Diego Garcia in the central Indian ocean and H01 near Cape Leeuwin off the southwest coast of Australia. We use the ISC catalogued earthquakes as templates to conduct template matching and obtain a more complete set of repeating earthquakes in 2005–2016 around the Nias Island off Sumatra. Adding these new detected earthquakes and using high-quality hydrophone data enable us to infer the large-scale ocean temperature changes with a high temporal resolution. For both H08 and H01, we detect not only seasonal signals generally consistent with that in previous oceanographic datasets of ECCO and Argo, but also more interesting features missing in ECCO and Argo. These results suggest that the global hydrophone network offers new opportunities for monitoring ocean warming.

Promotional text: We developed a novel and low-cost method of using acoustic waves recorded by CTBTO hydrophones from repeating natural earthquakes to infer basin-scale average ocean temperature changes.

O1.3-513 – Long-Term Observations of a Potential Great Whale Call from the Central Indian Ocean During 2002-2019

Author: Nikita R. Pinto[1]
Co-author: Tarun K. Chandrayadula[1]
[1]*Indian Institute of Technology Madras, Chennai, India*
Corresponding Author: nikitapinto8@gmail.com

This work presents observations of a potential great whale call at Diego Garcia (HA08N and HA08S). The whale calls which remain unidentified have only been referred to as the Diego Garcia Downsweep (DGD). The calls occur between 20-45 Hz, and constitute a set of tones similar to a comb, followed by a downsweep. The calls between 2002-2019 are used to present two analyses. The first shows that the DGD call-frequencies change across the years. The comb frequencies steadily increase, while that of the downsweep decrease but also branch into higher frequencies. The second set of results present angle and range estimates of the whale. For angle estimates this work uses a broadband beamformer which incoherently combines narrowband beamformer outputs across the multiple frequencies of the calls. For range, the work builds an Nx2-dimensional Parabolic Equation (PE) model to predict the received intensities across range. The model incorporates the local sound speed profiles, and the complicated bathymetry across a 1500 km area around HA08. The intensity predictions are compared against the received call levels to estimate ranges of the calling whales. Preliminary results show that the estimates pick out tracks of nearby whales, and some potentially distant calls.

Promotional text: Long-term recordings from the IMS stations at Diego Garcia suggest that the Indian Ocean abounds in marine mammal diversity, with several blue whale species. Recordings were used to study changing vocal behavior and migration paths of one potential whale species.

O1.3-648 – Using Ambient Noise at Hydroacoustic Stations for Passive Ocean Sensing

Author: Karim Sabra[1]
[1]*Georgia Institute of Technology, GA, USA*
Corresponding Author: karim.sabra@me.gatech.edu

Conventional acoustic remote sensing techniques typically rely on controlled active sources which can be problematic to deploy and operate over the long term – especially if multiple sources are required to fully illuminate the ocean region of interest – or may not even be available at very low frequencies (~10 Hz). Conversely, receiver arrays are becoming increasingly autonomous, and capable of long-term deployment thus enabling passive acoustics for ocean remote sensing applications by taking advantage of the ubiquitous ocean ambient noise. The archived ambient noise recordings made at the hydroacoustic stations of the Comprehensive Nuclear-Test-Ban Treaty (CTBTO) International Monitoring System (IMS), over decades at some locations, provide a unique platform for the scientific community to test this fully passive acoustic approach for ocean remote sensing. This presentation will present proof of concept of passive ocean remote methods using these hydroacoustic data such as passive acoustic thermometry to estimate deep ocean temperature variations and internal tides using coherent processing of low-frequency ambient noise. Challenges and opportunities for Ocean basin and global-scale passive ocean sensing will be discussed.

Promotional text: The archived ambient noise recordings made at the IMS hydroacoustic stations, over decades at some locations, provide a unique platform for the scientific community to investigate ocean remote sensing using passive acoustic.

O1.3-705 – SMART Subsea Cables for Observing the Ocean and Earth: An Update

Author: Bruce Howe[1]
[1]*University of Hawai'i at Mānoa, HI, USA*
Corresponding Author: bhowe@hawaii.edu

JTF SMART Subsea Cables (Joint Task Force, Science Monitoring And Reliable Telecommunications) is working to integrate environmental sensors (temperature, pressure, seismic acceleration) into submarine telecommunications cables. This will support climate and ocean observation, sea level monitoring, observations of Earth structure, tsunami and earthquake early warning and disaster risk reduction, with relevance to the CTBTO monitoring mission. Recent advances include regional SMART pilot systems that are initial steps to trans-ocean and global implementation. Building on the OceanObs'19 conference and community white paper (DOI 10.3389/fmars.2019.00424), this overview and description of the status of ongoing projects will include: The InSea wet demonstration project off Sicily at the EMSO Western Ionian Facility; Vanuatu and New Caledonia; Indonesia's Makassar Strait systems working toward systems for the Sumatra-Java megathrust zone and in the inner waters; and the CAM-2 triangle system connecting Lisbon, Azores and Madeira. Observing system design studies are reviewed. Funding reflects a blend of government, development bank, and commercial contributions. In addition to these notable scientific and societal benefits, the Telecom mission of societal connectivity will benefit as well, as environmental awareness improves both individual cable system integrity as well as that of the overall global communications network.

Promotional text: SMART Subsea Cables is integrating environmental sensors into submarine telecommunications cables to support climate and ocean observation, sea level monitoring, observations of Earth structure, tsunami and earthquake early warning and disaster risk reduction.

P1.3 The Oceans and Their Properties Abstracts of Poster Presentations

P1.3-095 – Global Hydroacoustic Simulations on High-Performance Computers

Authors: Noriyuki Kushida[1]; Tiago Oliveira[2]; Ying-Tsong Lin[3]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*University of Aveiro, Aveiro, Portugal*
[3]*Woods Hole Oceanographic Institution, Woods Hole, USA*
Corresponding Author: noriyuki.kushida@ctbto.org

The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) is operating and maintaining the international monitoring system of seismic, infrasound, hydroacoustic and airborne radionuclide facilities to detect a nuclear explosion over the globe. The monitoring network of CTBTO, especially with regard to infrasound and hydroacoustic, is quite unique because the network covers the globe, and the data is open to scientific use. On the other hand, global scale computer modelling of acoustic signal transmission has not been well established. In this presentation, improvements on such global acoustic transmission models will be presented with particular focus on high-performance computing.

Promotional text: Global acoustic computer simulation programs have been developed on cutting-edge computers to assist analysis of complex hydroacoustic signals.

P1.3-270 – Modular Nodes: Design and Development of a Novel Mechanism Which Enables the Repair of Individual Underwater Components in IMS Hydrophone Stations

Authors: Mario Zampolli[1]; Georgios Haralabus[1]; Jerry Stanley[1]; Geoffrey Cram[2]; Kevin Williams[2]; Michael Harrington[2]; Derek Martin[2]; Steven Schwennsen[2]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*University of Washington, Seattle, WA, USA*
Corresponding Author: mario.zampolli@ctbto.org

The six hydroacoustic hydrophone stations within the CTBTO's International Monitoring System comprise a total of 11 triplets. These triplets have a 20-year design life with no scheduled underwater segment maintenance actions and are based on a linear non-modular design which offers the advantages of high reliability and efficient deployment in one continuous operation. However, a triplet employing modular components and Wet-Mate Connectors (WMC) has an advantage in that replacement of a failed component(s) in-situ becomes possible without disturbing the remaining functional system components, or requiring replacement of the entire triplet. For these reasons a modular design triplet that maintains the efficient deployment of a non-modular linear system has been investigated. A critical component that has been developed is a latch mechanism that secures the cable terminations to the node structure. This isolates the WMC plug and the cable from the deployment stress which they are otherwise unable to sustain. After deployment, the latch can be opened; should a repair then become necessary, detachment of the cable and termination can be undertaken by an ROV. The design principles, the status of fabrication and testing of the modular cable latch are presented, along with the envisaged development of a prototype.

Promotional text: A modular component was developed to enable in-situ repair of hydroacoustic underwater triplets down to component level, while at the same time preserving the advantages of the robust and efficient deployment of the legacy linear triplets.

P1.3-273 – Could Short Duration Broadband Signals Identified in IMS Hydrophone Recordings Be Right Whale Vocalizations?

Authors: Mario Zampolli[1]; Peter Louring Nielsen[1]; Georgios Haralabus[1]; Jerry Stanley[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: mario.zampolli@ctbto.org

The six CTBT IMS hydroacoustic hydrophone stations, comprising 11 triplets in total, record continuous data sampled at 250 Hz. Marine mammal vocalizations are frequently identified in these recordings and form an integral part of the HA stations' undersea soundscapes, as reported in numerous scientific publications. During regular IMS hydrophone data quality checks, occasional short duration broadband signals occupying the entire available bandwidth were identified, which differ from the longer duration sweeps and chirps of whale calls reported in prior studies that made use of IMS hydrophone data. When such a sound appears on more than one hydrophone of a triplet, the recordings show amplitude variations across hydrophones that are indicative of a nearby source. Furthermore, the signals do not show signs of dispersion from long-distance propagation. The hypothesis is formulated that these sounds may be the low-frequency portion of short impulsive broadband vocalizations, referred to in the literature as Right Whale "gunshots". Recordings of this endangered species are relatively rare compared to vocalizations from other whales and their study is receiving increased interest from the scientific community.

Promotional text: It is hypothesized that short duration broadband signals observed at IMS hydrophone stations may be the low frequency end of impulsive Right Whale calls. Recordings from this endangered species are relatively rare compared to vocalizations from other whales.

P1.3-284 – A Self-Consistent Estimate of the CTBT IMS Hydrophone Locations Using Scientific Airgun Data from the CEVICHE Trial (Chile)

Authors: Peter Louring Nielsen[1]; Mario Zampolli[1]; Ronan Le Bras[1]; Pierrick Mialle[1]; Georgios Haralabus[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: peter.nielsen@ctbto.org

The CTBT IMS hydroacoustic sensor network composed of 6 hydrophone stations and 5 T-phase is part of the global CTBT verification regime. The hydrophone stations consist of hydrophone triplets. Each hydrophone is suspended in the ocean at a depth close to the SOFAR channel axis and anchored by a riser cable to the ocean floor. The geometry of the triplets and dedicated data processing allow for estimating the direction of arrival (or back-azimuth) of an incoming signal used for localizing the event. An accurate deployment position of each hydrophone in the triplet is essential to obtain an accurate location of an event by back-azimuth estimation that may originate thousands of kilometers from the triplet. CTBTO has in the past developed an algorithm calculating re-location of hydrophones based on numerous analyst reviewed event locations obtained by the entire CTBT IMS sensor network. In this study, the algorithm is applied to the HA03 hydrophone station to estimate possible corrections to the hydrophone locations. The Progressive Multi-Channel Correlator algorithm is updated with the hydrophone re-location, and a series of signals from a scientific airgun survey recorded during the CEVICHE trial (Chile) demonstrates the improvement in back-azimuth estimates by the hydrophone re-location.

Promotional text: Verification and validation of hydrophone deployment positions are beneficial for maintaining accurate event localization using the CTBT verification technologies.

P1.3-291 – IMS Hydroacoustic Hydrophone Station Detections Associated with Volcanic Eruptions at Kadovar Island, Papua New Guinea

Authors: Hiroyuki Matsumoto[1]; Mario Zampolli[2]; Georgios Haralabus[2]; Jerry Stanley[2]; James Robertson[2]; Nurcan Meral Özel[2]
[1]*Japan Agency for Marine-Earth Science and Technology, Yokosuka, Kanagawa, Japan*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: hmatsumoto@jamstec.go.jp

Following an eruption series at Kadovar Island, Papua New Guinea, the hydroacoustic datasets acquired by CTBT International Monitoring System (IMS) hydroacoustic (HA) hydrophone station HA11, Wake Island, were examined. HA11 is located approximately 3500 km northeast from Kadovar. Active eruptions restarted in January 2018 after a quiet period of three centuries. Cross-correlation analysis using two months of HA11 triplet data showed that the cumulative number of HA detections increased with time after commencement of the volcanic eruption series. According to local observations of Kadovar, a first eruption at the summit of the island was followed by four additional new vent spots and two vents were created near the shoreline. Our analysis suggests that the hydroacoustic signals detected by HA11 were associated with the volcanic eruptions near to the shoreline. A flank collapse resulting in erosion of the shoreline occurred on 9 February 2018. Hydroacoustic signals of long duration and small amplitude recorded at HA11 could be associated with this flank collapse. The present study demonstrates the potential contributions of the IMS HA stations data to the remote monitoring of underwater volcanic activity over large ocean areas.

Promotional text: A volcanic eruption series at Kadovar Island, Papua New Guinea, was remotely observed by IMS Hydroacoustic hydrophone station HA11, Wake Island. In addition to the eruptive events, the data also contained some small amplitude signals that associated with a flank collapse event.

P1.3-331 – Remote Detection of Hydroacoustic Signals Potentially Associated with the Sinking of *SS El Faro* Using CTBT IMS Hydrophone Data

Author: Dirk Metz[1]
Co-authors: Peter Louring Nielsen[2]; Mario Zampolli[2]; Georgios Haralabus[2]
[1]*Japan Agency for Marine-Earth Science and Technology, Yokosuka, Kanagawa, Japan*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: dmetz@jamstec.go.jp

On 1 October 2015, the cargo ship SS El Faro was lost approximately 120 km east of Long Island, The Bahamas, during the Hurricane Joaquin. Here, we analyze underwater sound phases potentially associated with the loss of this vessel, recorded by station HA10 of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) International Monitoring System (IMS) located at Ascension Island, Mid-Atlantic Ocean. Results from progressive multi-channel correlation and spectral analysis of broadband arrivals at both hydrophone triplets of HA10 suggest that at least one impulsive, in-water event occurred within minutes after communication with SS El Faro had ceased and emergency buoys were activated. The derived event origin notably coincides with the confirmed location of the wreckage on the seafloor. Our findings are consistent with results from 2D transmission loss modeling and further highlight the exceptional capabilities of the IMS hydroacoustic network for detecting both natural and non-natural events in the global ocean.

Promotional text: Using hydrophone data recorded at IMS station HA10, Ascension Island, we investigate underwater sound phases potentially linked to the sinking of the cargo ship SS El Faro during the 2015 Hurricane Joaquin.

P1.3-402 – Capability of the IMS Hydrophone Station Network to Characterize Low Level Underwater Seismicity, Underwater Volcanism and Iceberg Events

Author: Julien Vergoz[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: julien.vergoz@cea.fr

The hydroacoustic component of the IMS network consists of a series of five island-based seismic stations and six cabled hydrophone installations located in the Indian, Pacific and Atlantic Oceans. In this study, we focus only on hydrophone stations, which provide low back ground high quality data: each one of these stations hosts a set of three hydrophones deployed at a depth of the SOFAR channel, as a small-aperture (~2 km) horizontal triangular array. The direction of arrival and the apparent velocities of broadband acoustic arrivals can be determined from array processing based on correlation or beam forming techniques, therefore enhancing the detection and location capabilities of such a sparse network. Several years of data are processed with DTK-PMCC detector and global association is performed to build automatic events. The precision of estimated wavefront parameters allows to image with an unexpected accuracy the spatial locations of active seismic areas associated to ridge, subduction and volcanic seismicity, for which propagation paths are not blocked by bathymetric structures. Antarctica iceberg events are also clearly detected with season-dependent locations. Obtained seismic events are compared to LEB events, and differences are discussed in terms of location accuracy, source energy level and ground-to-water coupling.

Promotional text: This presentation demonstrates the capability of the IMS hydrophone stations network to characterize low level underwater seismicity, underwater volcanism and iceberg events.

P1.3-408 – Acoustic Energy Propagation in the Ocean Along Areas of Strong 4-Dimensional Sound Speed Variability

Authors: Emanuel Coelho[1]; Kevin Heaney[1]
[1]*Applied Ocean Sciences, LLC*
Corresponding Author:
emanuel.coelho@appliedoceansciences.com

The ocean is subject to complex dynamics that can produce time variant sound speed gradients with horizontal scales with potential to impact medium to high frequency acoustic propagation. Some of these features can critical grazing angles that may result in horizontal sound refraction, producing areas of stronger and weaker energy, time delays in the acoustic arrivals and changes on multi-path characteristics. The operational ocean forecast systems have skills to resolve some of these processes, but the acoustic propagation modeling solutions need to be able to handle these complex sound speed fields in order to reproduce the resulting sharp loss/gain changes along levels and directions (3D effects). These features can impact the accuracy of algorithms estimating source localization or doing ocean tomography and data assimilation. This work outlines a framework to diagnose when sound speed variability may be strong enough to trigger these 3-D effects following a risk management approach. It uses real-time ocean model forecasts, to build diagnostic variables estimating the possible acoustic impacts of ocean frontal systems and instabilities. The resulting analysis can be used to select numerical solution approaches and/or to create awareness regarding possible errors in the interpretation of acoustic signals in areas subject to strong dynamics.

Promotional text: This work includes a contribution relevant to the analysis of acoustic wave speed and attenuation, used for locating seismoacoustic disturbances in the oceans.

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

P1.3-425 – Recording of T Phases from the 7.4 M Kermadec Trench Earthquake in 2020 at the CTBT IMS HA3 Hydrophone Station

Authors: Tiago Oliveira[1]; Ying-Tsong Lin[2]; Sergio Jesus[3]; Peter Louring Nielsen[4]; Noriyuki Kushida[4]
[1]*University of Aveiro, Portugal*
[2]*Woods Hole Oceanographic Institution, Massachusetts, USA*
[3]*University of Algarve, Portugal*
[4]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: toliveira@ua.pt

On 18 June 2020, energetic underwater acoustic T-phase signals were recorded at the Comprehensive Nuclear-Test-Ban Treaty (CTBT) International Monitoring System (IMS) hydrophone station HA03, located at the Juan Fernandez Islands, Chile. In this work, we investigate the origin of these T-phases, which were associated to an M7.4 submarine earthquake with epicenter in the Kermadec Trench located at a distance of approximately 8700 km from HA03. Analysis of the recorded T-phases was performed using the Progressive Multi-Channel Correlation algorithm (DTKGPMCC) installed on the CTBTO virtual Data Exploitation Centre (vDEC). This analysis revealed a strong signal correlation between North and South HA03 hydrophone arrays, different arrivals were identified within the duration of the earthquake, and the estimated back azimuth showed variability over time. The back azimuth results suggest that T-phases could be triggered at different locations along the Trench and far from the declared earthquake epicenter. Underwater acoustic signal travel times were estimated along different propagation paths by a Normal Mode model with realistic environmental input, and possible horizontally reflected and diffracted paths were calculated by a 3D Parabolic Equation model. Future research directions for the improvement of localization T-phase excitation from submarine earthquakes will be discussed.

Promotional text: Propagation of low-frequency underwater acoustic signals (5 to 20 Hz) from the 18 June 2020 M7.4 Kermadec Trench earthquake is investigated. This analysis will provide guidance on future improvements of underwater event localization using the CTBT IMS hydroacoustic sensor network.

P1.3-490 – A Theoretical Formulation of a 3-D Acoustic Propagation Model for Stratified Oceanic Media Based on an Indirect BEM Approach

Authors: Juan D. Gonzalez[1]; Edmundo F. Lavia[1]; Silvia Blanc[1]
[1]*Argentinian Navy Research Office, Ministry of Defence, Buenos Aires, Argentina*
Corresponding Author: juanrst@hotmail.com

Despite the progress made both in hardware and numerical techniques, 3D acoustic propagation for stratified oceans in cartesian coordinates, is still a challenge. In 2019, an approach to this problem restricted to short-range distances, using the Boundary Element Method (BEM), was reported (Li et al. J. Comput. Phys. 392, (2019): 694-712.). The BEM is a widespread method that exhibits certain useful advantages for solving time-harmonic scattering problems such as the fact that only integration in 2D boundaries is required, the Sommerfeld radiation condition is automatically satisfied, there is no need to add artificial absorbing layers and the seawater-seabed interface can be managed quite easily. The main disadvantage is that a non-homogenous medium like the oceanic environment must be modelled as a multi-domain problem which makes it computationally expensive and big enough to require using of iterative solvers as the Generalized Minimal Residual Method (GMRES) in addition to techniques for accelerating the evaluation of surface integrals. Here, an indirect BEM formulation, characterized by providing a more stable solution than the direct approach adopted in the previously mentioned work, which needs preconditioners to solve the involved linear system, is developed from its theoretical foundations through numerical evaluation of some representative benchmark situations.

Promotional text: Acoustic propagation modelling in the ocean is a key component to analyse and understand received signals

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

at hydroacoustic stations. Research on new improved methods, as the one presented here, is expected to generate further and direct impact on improving nuclear test monitoring.

P1.3-494 – An Inverse Problem Approach for Acoustic Transmission Loss Estimation from the Analysis of Signals Generated by Seismic Airgun Arrays

Authors: Igor Prario[1]; Mariano Cinquini[1]; Rui Marques Rojo[1]; Silvia Blanc[1]; Patricio Bos[1]
[1]*Argentinian Navy Research Office, Ministry of Defence, Buenos Aires, Argentina*
Corresponding Author: iprario@fi.uba.ar

Offshore seismic surveys with airgun array sources are currently widespread in all the oceans. They constitute one of the most powerful and systematic impulsive noise sources in marine environments. The sound pulses from large airgun arrays generate signals that contain sufficient energy in the 5-60 Hz band to propagate ocean-basin scales at ranges of hundreds to thousands of kilometres. Under favourable propagation conditions they can be received at the CTBT IMS hydroacoustic stations (HA) with high signal to noise ratio. Unlike previous work, our focus is neither to study their effects on marine species nor to investigate the stratified sedimentary structure of the seabed, but to evaluate whether these signals can be used to validate theoretical predictions of propagation models. A sample of recorded signals from seismic surveys obtained from the IMS HA historical data is exhaustively analysed through cepstral, spectral and time-based techniques. Then, based on the known characteristics of the energy source spectral density of airgun arrays below 100 Hz, as published in the literature, some underwater propagation properties are inferred.
Promotional text: Validating sound propagation models in oceans contributes to improve the nuclear test monitoring and verification. The present work is a scientific application of data used for test ban verification with the consequent feedback to the CTBTO and the broader scientific community.

P1.3-526 – Modeling of Hydroacoustic Propagation Based on the Normal Mode Parabolic Equation Method

Authors: De Nan[1]; Jian Li[1]
[1]*CTBT Beijing National Data Center, Beijing, China*
Corresponding Author: nan.de@ndc.org.cn

In view of the low accuracy of the far-field modeling of underwater explosion sound propagation, the normal mode-parabolic equation method is used to carry out the modeling of hydroacoustic propagation to optimize the ability of far-field propagation simulation. This method combines the advantages of the normal mode model method and the parabolic equation method, adopts local normal mode analysis in the vertical direction, and uses the parabolic equation method to solve the normal mode amplitude equation in the horizontal direction. This method can be used to simulate the sound propagation loss of underwater explosions, and combined with the sound velocity profile, the theoretical travel time of sound propagation can be calculated. This method solves the problem that the high frequency situation is hard to calculate with the parabolic equation method, and the algorithm is able to extended to three-dimensional simulation.
Promotional text: Use new method to optimize the ability of Modeling of hydroacoustic propagation.

P1.3-546 – Observed Laterally Reflected Hydroacoustic Signals Generated by Underwater Impulsive Sound Sources

Author: Ivana Jukic[1]
Co-authors: Peter Louring Nielsen[1]; Ronan Le Bras[1]; Paulina Bittner[1]; Aaron Joseph Gutierrez Jimenez[1]; Baby Jane Punongbayan[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: ivana.jukic@ctbto.org

The International Monitoring System (IMS) of the CTBTO includes hydroacoustic stations composed of underwater hydrophones placed at the depth of the SOFAR channel. Since the hydroacoustic component of the network is designed to detect underwater nuclear explosions, events of special interest are impulsive underwater explosions. Among these, we studied several underwater explosions detonated close to the coast of Florida in September 2016 and 4 impulsive-like events (likely also underwater sources) from the Kamchatka area recorded in August 2020. In both cases, we observe secondary arrivals on IMS station HA11 for the Kamchatka sources and HA10 for the Florida sources immediately following the direct hydroacoustic arrivals. We assume these secondary arrivals are due to coastal reflections. We identify the potential reflection points for these reflections based on their back azimuths at the recording station and the estimated location of the impulsive sources. To verify this, we used the IDC standard hydroacoustic analysis tool HART and DTK-(G)PMCC, the latter provided to CTBTO authorized users, to estimate back azimuths. Comparisons between sources in the same general area give us an idea of the consistency of these reflections between sources in the same general area.

Promotional text: From this study of reflected hydroacoustic signals generated by underwater impulsive sources it is evident that the IMS in-water hydroacoustic stations can detect signals of high relevance to CTBTO and also that the IDC processing analyst tools are applicable to define them.

6.2. Theme 2: Events and Nuclear Test Sites

Events such as earthquakes, explosions and releases of radionuclides produce signals and surface features that may be observed locally, regionally, nationally or globally. Such events can be located in time and space, and their characteristics can be estimated based on the data collected. This theme covers the characterization of the source, the emitted signals, and what these reveal about the event and its environment. Only if the source is well characterized can its associated signals and anomalies be correctly analysed and interpreted. To ensure compliance with the Treaty, it is essential to understand the full extent of signals that may be generated by a nuclear explosion, as well as to be familiar with any other seismic, hydroacoustic, infrasound, radionuclide or other signals that could be confused with those from a nuclear explosion.

The Treaty's provision for OSI depends upon knowledge of the observables that may be expected after a nuclear test and how these could be identified as geophysical, radioactive, temperature or other anomalies or artefacts of testing. While such observations can help distinguish between inactive and active nuclear weapon test sites, the data recorded by IMS stations also make it possible to differentiate nuclear tests from other human made or natural events, thereby serving as a unique reservoir of knowledge for better informed policy making.

One of the challenges facing an inspection team at a historical test site is the need to distinguish and identify observables generated by historical underground nuclear explosions (those conducted before the nuclear testing moratorium) and those resulting from a more recent event. Factors to consider could include recognizing features that may indicate a decommissioned and decontaminated site or those that may suggest an active or reopened site. The types of expertise and capabilities required for these purposes need to be elaborated and could become relevant if any contingency operations that would call upon CTBTO technological capabilities are agreed by the United Nations and the States Signatories.

T2.1 Characterization of Treaty-Relevant Events

Highlights

Events in the Democratic People's Republic of Korea

O2.1-275 reported on detections at IMS hydrophone stations of primary and tertiary phases from the sixth announced underground nuclear test by the Democratic People's Republic of Korea (3 September 2017, DPRK6). These appear to be the first detections of this kind at IMS hydrophone stations. Primary seismic phases, or P phases, were identified at four of the six CTBT IMS hydroacoustic hydrophone stations. The signals match P phase arrival times for these stations, with the exception of one station, where the arrival time matches a path through the outer core. In addition, T phases originating from the event were detected at the station nearest to the test, with arrival times consistent with a P phase travelling from the source through the earth's crust, to an offshore location along the Japan Trench, and from there along water borne paths to both triplets of HA11 (USA).

P2.1-643 provided a comprehensive overview of how ATM supported the analysis of radionuclide detections from tests in the Democratic People's Republic of Korea. In several cases, measurements of releases from nuclear facilities caused ambiguous radioxenon detections in the aftermath of the tests. There were matching isotopic ratios and fitting atmospheric conditions for only two tests (2006, 2013). Results for two other tests were consistent but not conclusive, with detections of ^{133}Xe only (January 2016, 2017). For two other tests (2009 and September 2016), it was not possible to identify potentially related radioxenon detections.

P2.1-123 performed discriminant analyses combining cross-spectral Pg/Lg and Pn/Lg from regional stations to categorize seismic events that occurred in the Democratic People's Republic of Korea from 2006 to May 2020, including the six declared nuclear tests, the cavity collapse and earthquakes triggered by the 3 September 2017 test, and two recent seismic events (27 June 2019, 11 May 2020). The analysis was able to separate the cavity collapse from the population of nuclear explosions. However, the distinction between the earthquakes and the cavity collapse is ambiguous. The analyses also confirm that the recent southern events are both tectonic earthquakes that occurred naturally.

P2.1-162 discussed the possibility to improve the resolution of the isotropic seismic moment tensor using rotational ground motions. The isotropic feature is crucial to discriminate explosive sources from other sources that may indicate a nuclear test. The method was demonstrated in a synthetic set-up for the Korean peninsula and analysed the 2013 nuclear test by the Democratic People's Republic of Korea. Applying a Bayesian inversion method, three frequency bands were tested, as well as inversion with Green's functions based on 1-D and 3-D structural models. The reliability of determining the isotropic part was increased. As portable rotation sensors dedicated for seismological applications have recently become available, the authors suggest that rotational ground motions offer a new opportunity for improving nuclear-test verification.

P2.1-371 reported the development of a rapid and automated full seismic source characterization method called GRiD MT that reveals the main parameters of any events with magnitude above 3.5 within a few minutes. The method was implemented over the Democratic People's Republic of Korea region using only a limited number of seismic stations, correctly identifying all announced nuclear tests by the country (including the smallest one in 2006).

Beirut Port Explosion

A special subsection under this topic focused on results from the analysis of signals captured following the tragic explosion at the Port of Beirut in Lebanon on 4 August 2020. The devastating shock wave resulted in more than 200 fatalities, injured thousands and caused immense damage to buildings and infrastructure. The explosion triggered seismic, acoustic, infrasound and hydroacoustic signals that propagated through the lithosphere, atmosphere and hydrosphere. The effects of the shock wave were also captured on video. The presentations merged information from various sensors and technologies of the CTBT monitoring system to estimate the yield of the event. Most yield estimates were in the range of 0.5–1 kt, which is plausible given the reported 2.75 kt of ammonium nitrate as the explosive source, only part of which contributed to the explosion. O2.1-656 observed that considering previous ammonium nitrate explosions, it seems that efficiency and TNT equivalence are 1 kt AN ~ 0.42 kt eq. TNT. Exact estimates from seismic data are complicated owing to the uncertainty of the coupling of the above-ground explosion to seismic waves.

O2.1-228 reported on a multi-technique analysis of seismological, hydroacoustic, infrasonic and radar remote sensing data. It estimated the explosive yield of the Beirut port explosion to be equivalent to 0.8–1.1 kt of TNT. O2.1-191 and P2.1-195 illustrated consistency between the estimated yields using videos of the blast and seismic waveforms. Shockwaves recorded by personal mobile phones and cameras and sensor data were used to obtain the arrival times at various ranges. Using published empirical and theoretical relationships, the yield estimates were 1 kt of TNT or less. These yield estimates were consistent with the analysis of P wave spectra, which were corrected for propagation and attenuation.

O2.1-290 analysed signals from several local and regional seismological stations that recorded three different phases from this event, with velocities of 7.92 km/s, 1.34 km/s and 0.35 km/s. These phases represent P waves, hydroacoustic signals and shockwave signals, respectively. The signals were widely recorded in neighbouring countries and, in the case of infrasound, regionally. The location of the explosion was estimated accurately from the waveform data of the recording stations using the PMCC technique. Differential interferometric synthetic aperture radar (DInSAR) analysis verified the maximum damage area, extending 2 km around the blast site with 2 cm vertical displacement.

O2.1-656 estimated the explosive source parameters – including the yield – based on the analysis of regional seismic waveforms. Data provided by the seismic stations of the IMS were retrieved and processed, as well as open access regional waveforms provided by the Incorporated Research Institutions for Seismology (IRIS) and GEOFON network.

Other Events

P2.1-472 reported on the event analysis of Treaty-relevant radionuclides detected in the Nordic region in June 2020. P2.1-540 analysed signals from the fragmentation of a bolide, an explosion at a fireworks factory in Turkey and the Beirut explosion in 2020.

Techniques to Differentiate Between Real Events and Backgound

O2.1-208 discussed the implications of underground nuclear explosion cavity evolution for radioxenon isotopic composition. An often-used model for predicting the radioxenon composition of released gases actually yields a bound on isotopic compositions because it is based on an idealized cavity model. More realistic assumptions about the state of the detonation cavity produce isotopic activity ratios that differ from the civilian background more than the idealized standard model indicates, while also reducing the quantity of radioxenon available for atmospheric release and subsequent detection, and thus can improve the distinction between a nuclear explosion emission and the civilian background. Collapse of the cavity potentially has the greatest effect on the partitioning of the refractory fission products that are precursors to radioxenon.

P2.1-268 described the 3-D analysis of radioxenon isotopes that offers special opportunities for event screening and determining the event zero time. In the 3-D space, the analysis of timing and event screening can be separated. A time-independent screening can be achieved through the projection along the decay axis and the time. In this projection, event characterization can be achieved without knowledge about the time of the release from the source. The time-independent screening is most useful for Treaty-monitoring purposes because the time of origin of a remote detection is in general not known. In addition, under favourable conditions, the event origin time can also be determined irrespective of the source scenario by projecting the isotopic ratios on the decay axis.

P2.1-601 connected underground nuclear explosion gas-release ranges as aggregated from a set of scenarios with IMS radioxenon observations for evaluating isotopic activity ratios as indicators of a nuclear test. Mathematical modelling was used to create the relationship between radioisotope generation by a nuclear explosion and measurements in IMS samples. P2.1-486 presented the use of data-based kernel density equations for probability distributions of CTBT-relevant radioxenon isotopes at IMS stations in normal background from nuclear facilities and as simulated from underground nuclear explosions. P2.1-572 discussed the formation of uneven nuclear debris ‘hot’ particle deposition areas. Elevated $^{137}Cs/^{239,240}Pu$, $^{238}Pu/^{239,240}Pu$, $^{240}Pu/^{239}Pu$ isotopic ‘fingerprint’ values reliably reveal a nuclear event and assess its source by fusing these values with ATM.

O2.1-061 discussed how machine learning algorithms can be used to classify electromagnetic events as lightning or not lightning with high reliability. The results show that coincidences of an unrecognized electromagnetic signal with an infrasound detection are rare. It is suggested that measurements of electromagnetic fields may serve as a means of supporting infrasound signal analysis, as nuclear explosion is the only electromagnetic pulse source that also produces long range infrasound signals.

On-Site Inspection and Historical Sites

O2.1-420 described a new method to detect underground cavities from an underground nuclear explosion that uses the finite-interval spectral power of seismic ambient noise. The method requires measurements at a set of points (possibly irregularly distributed) at the earth's free surface around and above a suspected cavity. The authors verified the method using records from a site near Felsőpetény, Hungary, that were collected by the CTBTO during a field test in the framework of developing OSI capabilities. P2.1-474 discussed an evaluation of the viability of ^{39}Ar as a potential long term indicator of underground nuclear explosions as it compares to ^{37}Ar, with simulations demonstrating persistently detectable subsurface ^{39}Ar concentrations even decades after events.

O2.1 Characterization of Treaty-Relevant Events Abstracts of Oral Presentations

O2.1-061 – Matching Electromagnetic Measurements to Infrasound Signals

Authors: Maayan Ainas Kahlon[1]; Eliezer Lipshtat[1]
Co-author: Moshe Kushnir[1]
[1]*Soreq Nuclear Research Center, Yavne, Israel*
Corresponding Author: maayan@ndc.soreq-ndc.gov.il

Measurements of electromagnetic (EM) fields have been proposed as a means of supporting and aiding infrasound signal analysis. As opposed to nuclear explosion, other natural and man-made infrasound sources don't produce an EM signal. Thus, if an IS signal isn't accompanied by an EM pulse, it's known that it's not originated from a nuclear explosion. Lightning discharges are the main source of EM pulses. Due to their high abundance, fortuitous coincidence of lightning with an infrasound signal are a common situation. These events may be mistakenly assumed as a nuclear explosion. To avoid this obstacle, a reliable method for lightning detection and identification is required. EM events were detected and recognized using spectrogram. From each segmented event, both time and frequency domain features were extracted. Based on these features, and using machine learning algorithms, all the detected events could be classified as either lightning or not lightning event with high reliability. Then, the non-lightning events were matched with infrasound events. The results show that coincidences of an unrecognized EM signal with an infrasound detection are rare and thus do not impose a real limitation. We conclude that information from EM measurements may enhance and ease the analysis of infrasound signals.
Promotional text: Measurements of EM fields may serve as a means of supporting infrasound signal analysis. Nuclear explosion is the only EMP source which produces also long range infrasound signal. The results show that coincidences of an unrecognized EMP with IS is rare.

O2.1-191 – Yield Estimation of the 4 August 2020 Beirut Explosion Using Seismic and Shockwave Data

Author: Chandan Saikia[1]
Co-authors: Jon Creasey[1]; Mark Woods[1]; Petru Negraru[1]
[1]*Air Force Technical Applications Center (AFTAC), FL, USA*
Corresponding Author: chandanksaikia@gmail.com

This study uses seismic waveform and shockwave data from the Aug 4, 2020 Beirut explosion to investigate whether the yield estimated by the shockwave data can predict the spectral level observed in the seismic data. Many stations from the IRIS Data Management Center (DMC) recorded this explosion up to hundreds of kilometers with good signal-to-noise ratios (SNR). Shockwaves were recorded by personal phones and cameras, and are from social media platforms. These shockwave data were used to obtain the arrival times at various ranges. This dataset was augmented by additional data from Rigby et al. (2020). Shockwave data were modeled using published empirical and theoretical relationships, which suggested its yield to be around 1 Kt TNT. This estimate is in agreement with the value derived by Rigby et al. based on a relation they developed using the shockwave data from Kingary and Bulmash (1984). These yield estimates were used to determine the consistency with respect to the P-wave spectra, which were corrected for the propagation and attenuation effects. Accuracy of the relationships used by various investigators is also examined by validating against the shockwave data collected for other explosions with known yields.
Promotional text: Results illustrates the consistency between the yields estimated using videos from the social media of the blast vs. seismic waveforms. This paper presents a further validation of formulae used to associate the blast data to the yield based on the GT explosions.

O2.1-208 – Implications of Underground Nuclear Explosion Cavity Evolution for Radioxenon Isotopic Composition

Authors: Charles R. Carrigan[1]; Yunwei Sun[1]; Eric Pili[2]; Daniel Neuville[3]; Tarabay Antoun[1]
[1]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[3]*Institut de Physique du Globe de Paris, France*
Corresponding Author: carrigan1@llnl.gov

Isotopic ratios of radioxenon captured in the atmosphere can be indicators of the occurrence of an underground nuclear explosion. However, atmospheric background from civilian sources of xenon isotopes can interfere with detection of nuclear testing signals according to a standard model of the evolution of radioxenon isotopic abundances in a nuclear explosion cavity. We find that this standard model is idealized by not including the effects of physical processes resulting in the partitioning of the radionuclide inventory between a gas phase and rock melt and by ignoring seepage of gases from the cavity or collapse zone. More realistic assumptions about the state of the detonation cavity produce isotopic activity ratios that differ from the civilian background more than the idealized standard model indicates, while also reducing the quantity of radioxenon available for atmospheric release and subsequent detection. Collapse of the cavity potentially has the greatest effect on partitioning of the refractory fission products that are precursors to radioxenon. The model allows for the possibility that post-detonation seismicity can be used to predict isotopic evolution.
Promotional text: An often-used model for predicting the radioxenon composition of released gases actually yields a bound on isotopic compositions because it is based on an idealized cavity model. Improved predictions of suspect UNE signals may be realized using detailed cavity evolution models.

O2.1-228 – Yield Estimation of the 2020 Beirut Explosion Using Open Access Waveform and Remote Sensing Data

Authors: Christoph Pilger[1]; Peter Gaebler[1]; Patrick Hupe[1]; Andre Kalia[1]; Felix Schneider[2]; Andreas Steinberg[1]; Henriette Sudhaus[3]; Lars Ceranna[1]
[1]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
[2]*GeoForschungsZentrum GFZ, Potsdam, Germany*
[3]*Institut für Geowissenschaften, University of Kiel, Germany*
Corresponding Author: christoph.pilger@bgr.de

We report on a multi-technique analysis using publicly available data for investigating the huge, accidental explosion that struck the city of Beirut, Lebanon, on August 4, 2020. Its devastating shock wave led to thousands of injured with more than two hundred fatalities and caused immense damage to buildings and infrastructure. Our combined analysis of seismological, hydroacoustic, infrasonic and radar remote sensing data allows us to characterize the source as well as to estimate the explosive yield. The latter ranges between 0.8 and 1.1 kt TNT (kilotons of trinitrotoluene) equivalent and is plausible given the reported 2.75 kt of ammonium nitrate as explosive source. Data from the International Monitoring System of the CTBTO are used for infrasound array detections. Seismometer data from GEOFON and IRIS complement the source characterization based on seismic and acoustic signal recordings, which propagated in solid earth, water and air. Copernicus Sentinel data serve for radar remote sensing and damage estimation. As there are strict limitations for an on-site analysis of this catastrophic explosion, our presented approach based on openly accessible data from global station networks and satellite missions is of high scientific and social relevance that furthermore is transferable to other explosions.

Promotional text: A multi-technique analysis of the 2020 Beirut explosion using open access seismological, infrasonic and radar satellite remote sensing data to independently and consistently estimate the explosive yield in the order of 1 kt TNT.

O2.1-275 – Detections at IMS Hydrophone Stations of Primary and Tertiary Phases from the Sixth Announced Underground Nuclear Test by the Democratic People’s Republic of Korea

Authors: Mario Zampolli[1]; Peter Louring Nielsen[1]; Ronan Le Bras[1]; Paulina Bittner[1]; Georgios Haralabus[1]; Jerry Stanley[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: mario.zampolli@ctbto.org

Primary seismic phases, P-phases, associated with the sixth announced DPRK underground nuclear test of 3 September 2017 (DPRK6) were identified at frequencies below 4 Hz at four of the six CTBT IMS hydroacoustic hydrophone stations, namely HA01, HA03, HA08 and HA11. The signals match P-phase arrival times for these stations except for HA03, where the arrival time matches a path through the outer core. No P-phase detections were made at the two remaining stations, HA04 and HA10, likely because they fall within shadow zones of core phases. Moreover, T-phases originating from the DPRK6 event were detected at both triplets of the station nearest to the test, HA11 Wake Island, at frequencies below 10 Hz. The arrival times of these T-phases are consistent with a P-phase travelling from the source through the Earth’s crust, to an off-shore location along the Japan Trench where the bathymetry crosses the SOFAR channel and from there along water borne paths to both triplets of HA11. The back-azimuths of these T-phase arrivals point to this SOFAR crossing as the location where the P-phase coupled into the hydroacoustic paths. To the authors’ best knowledge, DPRK6 is the first nuclear test detected at IMS HA hydrophone stations.

Promotional text: P-phases from the 6th announced DPRK underground nuclear test were detected at four of the six IMS HA hydrophone stations. Additionally, a T-phase consistent with this event was also detected at HA11. These appear to be the first detections of this kind at IMS HA stations.

O2.1-290 – Seismoacoustic Signature of Beirut Port Explosion

Authors: Islam Hamama[1]; Mohamed Nabil Mohamed ElGabry[1]; Noha Medhat[1]; Hany Saber[1]; Adel Othman[1]; Mona Abdelazim[1]; Ahmed Lethy[1]; Sherif Elhady[1]; Hesham Hussein[1]; M. Yamamoto[2]
[1]*National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Egypt*
[2]*Kochi University of Technology, Kochi, Japan*
Corresponding Author: elgabry@nriag.sci.eg

A large amount of ammonium nitrate has exploded in Beirut port on 4 August 2020 leaving behind large destruction. The explosion has triggered seismic, acoustic, infrasound, and hydroacoustic signals that propagated through the lithosphere, atmosphere and hydrosphere. The signal was widely recorded in the neighboring countries and even in the case of infrasound, it has been reported regionally. In this work we document the seismo-acoustic signature of the event and try to investigate the size of the source and the deformation associated with it, using different techniques. DInSAR analysis verified maximum damage area, extending 2 km around the blast site with two cm vertical displacement. Several local and regional seismological stations recorded three different phases from this event with velocities 7.92 km/s, 1.34 km/s, and 0.35 km/s respectively. These phases represent P waves, hydroacoustic signals, and shockwave signals, respectively. The propagation modeling of the infrasound waves reflects a westward propagation towards I48TN, I26DE, and I17CI infrasound stations of the International Monitoring Stations (IMS) of the Comprehensive Test Ban Organization (CTBTO). The location of the explosion is estimated accurately from the waveform data of the recording stations using the technique of the Progressive multi-channel cross-correlation
Promotional text: The abstracts deal with a very unique event of the Beirut Explosion using regional data records for Seismic, Infrasound, and Hydroacoustic signal.

O2.1-420 – Detecting Underground Cavities Due to Underground Nuclear Explosions Using Seismic Ambient Noise

Authors: Jozef Kristek[1]; Miriam Kristekova[2]; Peter Moczo[1]; Peter Labak[2]
[1]*Comenius University, Bratislava, Slovakia*
[2]*Earth Science Institute, Slovak Academy of Sciences, Bratislava, Slovakia*
Corresponding Author: kristek@fmph.uniba.sk

Detection and location of a cavity generated by an underground nuclear explosion is an important proof in case of suspicion of violating the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The resonance seismometry is one of the CTBT's permitted techniques during an on-site inspection (OSI). We present a new method for detecting and locating a horizontal position of cavity which uses the Finite-interval Spectral Power (FISP) of seismic ambient noise. The method requires measurements at a set of points (possibly irregularly distributed) at the Earth's free surface around and over a suspected cavity. Because the method gives better results for undistorted segments of noise records, we also present a method of automatic identification of such segments. We verified our method using records from a site near the Felsőpetény, Hungary, which were collected by the CTBT Organisation during a field test in the framework of developing OSI capabilities. We also show that it is possible to make the noise measurements sequentially. The minimum number of simultaneously measured locations is two. This allows to perform additional measurements, if needed, or to use a limited number of seismometers. The FISP method is ready for further tests at other sites and applications.
Promotional text: How to detect and locate a cavity at a site of a suspected UNE using records of seismic ambient noise?

O2.1-656 – Source Parameters Estimation of the 4 August 2020 Beirut Explosion Using 3-D Seismic Modelling

Authors: Laurent Guillot[1]; Yoann Cano[1]; Gael Burgos[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Authors: laurent.guillot.blr@gmail.com, yoann.cano@cea.fr

On 4 August 2020, a very large explosion blew up the city of Beirut, the capital of Lebanon, causing many casualties and high damage, leaving an estimated of 300000 people homeless. The explosion was caused by a large amount of ammonium nitrate stored at the port of Beirut. The CEA undertook study in order to estimate explosive source parameters – including the yield – based on the analysis of regional seismic waveforms. Data provided by the seismic stations of the International Monitoring System (IMS) have been retrieved and processed, as well as open access regional waveforms provided by IRIS and GEOFON institute. A first approach involves empirical (or semi empirical) source model, corrected of depth effect, as preconized by Ford and Walter (2014). Those preliminary results are investigated using 3D full waveform modelling, focusing on continental regional propagation through middle-east territory. 3D Green's functions are convoluted with source term derived from seismo-acoustic coupling model. The study shows the contribution of simulation for the source analysis and parameters uncertainty mitigation.
Promotional text: Investigation about accidental explosion requires to perform every key-topics of the forensic seismology, including multi-technology analysis, detection, localization, source screening and source modelling.

P2.1 Characterization of Treaty-Relevant Events Abstracts of Poster Presentations

P2.1-123 – Discrimination of Seismic Events (2006 to 2020) in the Democratic People's Republic of Korea Using P/Lg Amplitude Ratios from Regional Stations and a Bivariate Discriminant Function

Author: Rigobert Tibi[1]
[1]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
Corresponding Author: rtibi@sandia.gov

Two events of magnitude (*mb*) 3.6-3.8 occurred in southern North Korea (NK) on 27 June 2019 and 11 May 2020. Although these events were located about 330-400 km from the known nuclear test site, the fact that they occurred within the territory of NK, a country with a recent history of underground nuclear tests, made them events of interest. We used P/Lg ratios from regional stations to categorize seismic events that occurred in NK from 2006 to May 2020, including the two recent events, the six declared NK nuclear tests, and the cavity collapse and triggered earthquakes that followed the 3 September 2017 nuclear explosion. We were able to separate the cavity collapse from the population of nuclear explosions. However, the distinction between the earthquakes and the cavity collapse is ambiguous. We used cross-spectral Pg/Lg and Pn/Lg ratios jointly in a quadratic discriminant function and successfully categorized the six declared nuclear tests and the triggered earthquakes that followed the September 2017 explosion. Our analyses also confirm that the recent southern events are both tectonic earthquakes that occurred naturally.
Promotional text: This study aligns with the SnT2021 goal of identifying methods for improving nuclear test monitoring and verification. The performed discriminant analyses suggest that combining cross-spectral Pg/Lg and Pn/Lg results in improved discriminant power.

P2.1-162 – Improving the Resolution of the Isotropic Seismic Moment Tensor Using Rotational Ground Motions

Author: Stefanie Donner[1]
Co-authors: Peter Gaebler[1]; Marija Mustac[2]; Babak Hejrani[3]; Hrvoje Tkalcic[3]; H. Igel[4]
[1]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
[2]*Faculty of Science, University of Zagreb, Zagreb, Croatia*
[3]*Australian National University, Canberra, Australia*
[4]*Department of Earth Sciences, LMU München, Germany*
Corresponding Author: stefanie.donner@bgr.de

Seismic moment tensors provide information not only about the geometry of a seismic source (tectonic – DC – part) but also with non-tectonic information such as volume changes (isotropic – ISO – part). This feature is crucial to discriminate explosive sources from others, which can hint to a nuclear test. However, that part is often not well resolved by standard methods. Measuring rotational ground motions might help to obtain more reliable results. Six components of ground motion are needed to entirely describe the seismic wave-field, three translational and three rotational. Just recently, portable rotation sensors dedicated for seismological applications are available. In previous studies, we show that by inverting both ground motions together, the resolution of the moment tensor can be improved significantly. In a synthetic set-up for the Korean peninsula we analysed the 2013 nuclear test of the Democratic People's Republic of Korea. Applying a Bayesian inversion method, we tested three frequency bands. We also tested the inversion with Green's functions based on one- and three-dimensional structural models. The reliability of the source mechanism benefits form both, the three-dimensional structure and rotations, even more in the higher frequency ranges. Thus, also the reliability of the ISO part is increased.
Promotional text: Rotational ground motion recordings contribute significantly to the reliable determination of moment tensors. Thus, discriminating explosive sources is better resolved. Therefore, rotational ground motions constitute an new opportunity for improving nuclear test verification.

P2.1-195 – Using Publicly Available Non-Seismic Constraints to Estimate the Yield of a Large Explosion in Beirut, Lebanon

Authors: Ileana Tibuleac[1]; Thomas VanDeMark[1]
[1]*Air Force Technical Applications Center (AFTAC), FL, USA*
Corresponding Author: ileana.tibuleac@us.af.mil

A study of a large explosion in Beirut, Lebanon, explores the use of non-seismic constraints to supplement the seismic data yield estimates. The explosion yield is estimated by fitting overpressure to the equivalent of a 1kT overpressure curve as a function of radius from the explosion ground zero. Overpressure is estimated using explosion damage evaluations from publicly available sources such as aerial photos, movies and press articles. An equivalent yield interval of 0.7-0.9-kT is estimated.
Promotional text: A study of a large explosion in Beirut, Lebanon explores the use of non-seismic constraints from publicly available sources to supplement the seismic data yield estimates.

P2.1-268 – Three Dimensional Space Analysis of Radioxenon Isotopic Activity Ratios for Characterizing a Nuclear Event in Comparison to Civilian Releases from Fission and Activation

Author: Martin B. Kalinowski[1]
Co-author: Kassoum Yamba[2]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Centre National pour la Recherche Scientifique et Technique (CNRST), Ouagadougou, Burkina Faso*
Corresponding Author: fairlir@yahoo.fr

This study on the nuclear release timing aims analysing radioxenon isotopic activity ratios in three dimensional space. The methodological approach and the characterization of the 3D usability threshold considered in this study were presented during SnT2019 and INGE2019. This presentation focuses on comparison to civilian sources from fission and activation. Obviously three isotopes are less likely to be detected simultaneously than two isotopes are. However, if three isotopes are available, making use of all three together offers a much more powerful analysis mechanism than with only two isotopes. In the three-dimensional space the analysis of timing and event screening can be separated. A time-independent screening can be achieved through the projection along the decay axis and the time. In this projection, event characterization can be achieved without knowledge about the time of the release from the source. The time-independent screening is most useful for CTBT monitoring purposes since the time of origin of a remote detection is in general not known. In addition, under favourable conditions, the event origin time can also be determined irrespective of the source scenario by projecting the isotopic ratios on the decay axis and scale it in units of time.

Promotional text: The 3-dimensional analysis of radioxenon isotopes offers special opportunities for event screening and determining the event zero time. For the former, time is eliminated by projecting the data along the axis of decay, the latter by projecting the data onto this axis.

P2.1-371 – Rapid and Automated Full Seismic Source Characterization: Seismic Monitoring Application for the North Korean Region

Author: Aurelie Guilhem Trilla[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: aurelie.trilla@cea.fr

Rapid full source characterization is strongly recommended for providing pertinent information after the occurrence of an event of interest such as a nuclear test. Full moment tensor inversion using long-period seismic waveforms recorded at regional distance has shown its relevance for confirming the isotropic component of a seismic source. In order to rapidly determine the full source parameters of events occurring in a region of interest, an automated grid-search moment tensor approach can be proposed. Here, we show that such method called GRiD MT reveals the main parameters of any events with magnitude above 3.5 within a few minutes: detection, origin time, location, moment magnitude and mechanism. We demonstrate its interest for seismic monitoring when implemented over the North Korean region using only a limited number of seismic stations. Correct identification of all past North Korean nuclear tests (including the smallest one in 2006) is rapidly obtained within an easy-to-use algorithm for a seismic analyst. Lastly, GRiD MT can be used for the monitoring of small to larger tectonic events, and is currently being tested and implemented for multiple objectives at the French National Data Center: nuclear test monitoring, earthquake monitoring, and tsunami warning.

Promotional text: This presentation shows the substantial interest for a national data center to develop and implement full source inversions in near-realtime for seismic event characterization.

P2.1-472 – Event Analysis of CTBT-Relevant Radionuclides Detected in the Nordic Region 2020

Authors: Ian Hoffman[1]; Pawel Mekarski[1]
Co-authors: Kurt Ungar[1]; Jing Yi[1]; Adrian Botti[1]; Michael Cooke[1]; Alain Malo[2]; Nils Ek[3]; Yves Pelletier[3]; Chris Cochrane[4]; Vladimir Khotylev[4]; Ali El-Jaby[4]; Anders Axelsson[5]; Klas Elmgren[5]; Tomas Fritioff[5]; Johan Kastlander[5]; Anders Ringbom[5]; Catharina Söderström[5]; Tero Karhunen[6]; Mikael Moring[6]; Aleksi Mattila[6]; Ashley Davies[7]; Matthew Goodwin[7]
[1]*Radiation Protection Bureau, Health Canada, Ottawa, ON, Canada*
[2]*Canadian Meteorological Centre (CMC), Dorval, QC, Canada*
[3]*Meteorological Service of Canada, Ottawa, ON, Canada*
[4]*Canadian Nuclear Safety Commission (CCSN), Ottawa, ON, Canada*
[5]*Swedish Defence Research Agency (FOI), Stockholm, Sweden*
[6]*Radiation and Nuclear Safety Authority (STUK), Helsinki, Finland*
[7]*AWE Aldermaston, Reading, United Kingdom*
Corresponding Authors: ian.hoffman@canada.ca, adrian.botti@canada.ca, pawel.mekarski@canada.ca

A series of measurements of multiple anomalous treaty relevant radionuclides at several measurement stations in Sweden and Finland, including the Stockholm aerosol sampler (SEP63) in the International Monitoring System (IMS), occurred in the summer of 2020. The cause and source of these radionuclides is still unknown. The laboratory re-measurement of the split IMS sample revealed that one-half of the split sample contained the entirety of the anthropogenic radioactivity - a high degree of sample inhomogeneity due to hot aerosol particles. Using the IMS results and by performing some advanced laboratory coincident measurement techniques, an international, multidisciplinary team started to unravel the details on the nature of this event while also demonstrating the verification benefits of adopting new sample analysis techniques.

Promotional text: Detections of multiple treaty relevant radionuclides by the IMS and national monitoring networks in June 2020 initiated an event analysis. An international, multi-disciplinary team employed multiple techniques including an advanced laboratory system to characterize this event.

P2.1-474 – Simulations of the Long-Term Evolution of Ar-39 Produced in an Underground Nuclear Explosion

Author: Justin Lowrey[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: justin.lowrey@pnnl.gov

Measurements of gas collected from locations surrounding historic underground nuclear tests have identified that Ar-39 produced during a nuclear explosion can remain in the subsurface decades after the event occurred. As an activation product produced by the interaction of neutrons with geologic potassium, Ar-39 is produced in significant quantities in almost any underground nuclear explosion. With a half-life of 269 years, the primary loss mechanism for Ar-39 over time is dilution in the atmosphere or the geology surrounding the event. In order to better understand how the transport of Ar-39 affects its viability as a long-lived underground nuclear explosion signature, a series of simulations were performed of an initially pressure-driven Ar-39 source with varying depth and geology type surrounding the source. The evolution of both Ar-37 and Ar-39 was modeled over 30 years and the loss to the atmosphere or to dilution in the surroundings was tracked.

Promotional text: This work discusses further evaluation of the viability of Ar-39 as a potential long-term indicator of underground nuclear explosions as it compares to Ar-37, with simulations demonstrating persistently detectable subsurface Ar-39 concentrations even decades after events.

P2.1-486 – Data-Based Kernel Density Equations for Probability Distributions of CTBT-Relevant Radioxenon Isotopes at IMS Stations in Normal Background from Nuclear Facilities and as Simulated from Underground Nuclear Explosions

Authors: Martin B. Kalinowski[1]; Boxue Liu[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: martin.kalinowski@ctbto.org

The objective of this study is to apply the kernel density (KD) approach to generate and investigate probability distributions of isotopic ratios for radioxenon releases from certain types of sources. KD equations for nuclear facility releases are derived from the data set of the radioxenon emission inventory of all nuclear power plants and all nuclear research reactors, as well as selected medical isotope production facilities in the calendar year 2014. Analytical equations for the releases from assumed underground nuclear explosions are obtained using Bateman equations for simple scenarios of prompt and delayed releases from underground nuclear explosions with in-growth and decay or alternatively with complete fractionation at time zero after the nuclear fission event. For both types of sources, KD equations will be linked with isotopic ratio calculations that connect source and receiver. The goal is to create probability density functions that could be applied e.g. with a Bayesian method to determine the probability whether an IMS observation could possibly be caused by a nuclear explosion.
Promotional text: This study presents data-based kernel density equations for possible nuclear test signatures and normal background. These can be used e.g. in a Bayesian method to determine the probability whether an IMS observation could possibly be caused by a nuclear explosion.

P2.1-487 – UK National Data Centre: Radionuclide Event Analysis

Authors: Matthew Goodwin[1]; Ashley Davies[1]; Richard Britton[2]; Daniel Chester[1]
[1]*AWE Aldermaston, Reading, United Kingdom*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: matthew.goodwin@awe.co.uk

The UK National Data Centre (NDC) operates a series of custom-developed software tools for the automatic processing, analysis, archiving and interpretation of radionuclide (RN) data from the International Monitoring System (IMS). The tools include an RN Pipeline for the analysis of radionuclide data (noble gas and particulate), and a series of simulation pipelines to provide accompanying atmospheric transport modelling (ATM) data. The ATM products are triggered on the identification of an 'RN detection event', which can include radioxenon plumes or 'high-priority' detections. An overview of the toolset is presented, along with case-studies using interesting RN detections from recent years, such as particulate detections at SEP63 and RUP61 during 2020.
Promotional text: The UK National Data Centre (NDC) has developed methods for the analysis and interpretation of radionuclide events. Here they are used to present results from the analysis of radionuclide detections on the IMS.

P2.1-540 – Forensic Event Analyses at the Turkish NDC

Author: Korhan Umut Semin[1]
Co-authors: T. Cem Destici[1]; Ocal Necmioglu[1]; Serdar Kocak[1]; Fatih Turhan[1]
[1]*Bogazici University, Istanbul, Turkey*
Corresponding Author: korhanse@boun.edu.tr

During the year 2020, apart from the global pandemic, there have been several global incidents that were recorded by IMS stations. As Turkish NDC, we have selected three of these events to be analyzed. The first event is the fragmentation of a meteorite/bolide on 27 May 2020 that was observed by many cities over the Northeastern part of Turkey, the second event is the Fireworks factory explosion at the outskirts of Sakarya city of Turkey occurred on July, 3rd and the last event that was analyzed is the explosion of 2.7 kT Ammonium Nitrate at the harbor of Beirut, Lebanon on 4 August 2020. Since all of these events occurred on the surface or the atmosphere, several IMS infrasound stations detected the acoustic pressure changes over great distances. In addition to the IMS infrasound stations, local seismic stations in Turkey recorded the ground vibrations caused by the shock waves of these events. Therefore, we were able to make an event analysis using fusion of both technologies to test not only our NDC's capabilities but also the products and tools that were provided by CTBTO. Our final analysis results will be presented at SnT 2021.

Promotional text: This work just shows the mutual benefits between CTBTO and NDCs. Characterization of an interesting event can be achieved through data fusion. NDCs can access to various global data through IDC to conduct in-depth analyses.

P2.1-572 – Nuclear Debris Characterization by Fission Isotope Assessment

Author: Andrius Puzas[1]
Co-authors: Rasa Gvozdaite[1]; Arunas Gudelis[1]; Vida Juzikiene[1]; Ruta Druteikiene[1]; Dalis Baltrunas[1]; Marina Konstantinova[1]; Vidmantas Remeikis[1]
[1]*Center for Physical Sciences and Technology, Vilnius, Lithuania*
Corresponding Author: andrius.puzas@ftmc.lt

Radionuclide isotopic composition analysis is an important and reliable tool for determination of the artificial radionuclide source. As each anthropogenic emission could be characterized by its own unique radionuclide composition, these "fingerprints" make it possible to determine the evidence of radionuclide contamination source. Gamma spectrometric measurements were performed with the state-of-the-art "Ortec" alpha spectrometer and gamma spectra were recorded by SILENA gammaspectrometric system with an HPGe coaxial detector. Radionuclide isotopic ratios were measured by a high resolution sector field mass spectrometer combined with a high sensitivity APEX sample introduction system. Elevated ^{137}Cs/^{239,240}Pu, ^{238}Pu/^{239,240}Pu, ^{240}Pu/^{239}Pu isotopic "finger print" values reliably reveal a nuclear event and assess its source by fusing these values with atmospheric transport modelling. The report discusses the areas of uneven "hot" particle deposition and large, vast "hot" spots.

Promotional text: The report discusses the formation of uneven nuclear debris "hot" particle deposition areas and covers large, vast "hot" spots assessment accomplished during radionuclide monitoring.

P2.1-601 – Connecting Underground Nuclear Explosion Gas Release Ranges as Aggregated from a Set of Scenarios with IMS Radioxenon Observations for Evaluating Isotopic Activity Ratios as Indicators of a Nuclear Test

Author: Martin B. Kalinowski[1]
Co-authors: Boxue Liu[1]; Charles R. Carrigan[2]; Yunwei Sun[2]; Steven Kreek[2]; Tarabay Antoun[2]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: martin.kalinowski@ctbto.org

Isotopic activity ratios of radioxenon measured in IMS noble gas samples are routinely obtained that might indicate a gas release from an underground nuclear test, although actually caused by atmospheric emissions from nuclear facilities. A robust method is required that tests the isotopic activity ratios of samples of special interest against a set of all relevant release scenarios that could possibly explain the source. This presentation treats nuclear explosions as the source. The method presented here combines the two ends of the lifetime of radioxenon isotopes and their activity ratios. One end is the

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

radioisotope generation by a nuclear explosion, the other end is their measurement in IMS samples. Mathematical modelling is used to create the relationship between both ends. Recent research results on the source mechanisms including in-growth and decay, cavity-melt fractionation and seepage of cavity gases are used to develop best-estimate input source terms as well as minimum and maximum activity ratio boundaries as a function of time. The ratios in the IMS sample are reconstructed as a function of the time of release into the atmosphere and the sampling time. The output is a score for the consistency of a set of scenarios with the observation.
Promotional text: Investigating IMS noble gas samples for possible nuclear test signatures requires all possible underground nuclear test scenarios to be considered. This presentation shows how the aggregated signature of all scenarios can be connected with IMS observations of a specific event.

P2.1-643 – Atmospheric Transport Modelling for Potential Releases and Detections Possibly Connected with Announced Nuclear Tests by the Democratic People's Republic of Korea

Authors: J. Ole Ross[1]; Lars Ceranna[1]
[1]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
Corresponding Author: ole.ross@bgr.de

Various techniques of Atmospheric Transport Modelling were applied after announced DPRK nuclear tests in order to support the analysis of potentially connected radionuclide detections. Forward dispersion forecasts from the test-site predicted potentially affected IMS stations; forward ATM for known background sources assessed their potential contribution to measured concentrations. In case of detections, backward ATM has shown consistency with certain emitter locations and identified coincident source regions for multiple detections. As we think that DPRK test 2017 could and must have been the last nuclear test at all, the presentation gives a comprehensive overview how ATM supported the analysis of the National Data Centre. Special focus is how potential interference with known background sources had an impact on the assessment. In several cases measurements of releases from nuclear facilities caused ambiguous radioxenon detections in the aftermath of DPRK tests. Finally, for two DPRK tests (2009 and 2016-Sep) it was not possible to identify potentially related radioxenon detections, for two tests there were consistent but not conclusive detections of Xe-133 only (2016-Jan, 2017) and for two tests there were matching isotopic ratios and fitting atmospheric conditions (2006, 2013).
Promotional text: The application of Atmospheric Transport Modelling in the aftermath of DPRK events gave crucial information and increased usefulness of potentially connected radioxenon detections and non-detections.

T2.2 Challenges of On-Site Inspection

Highlights

Topic 2.2 addressed various aspects of OSI, including the functioning and use of the Operations Support Centre, the potential use of compact portable cognitive satellite communication systems for in-field communication, aspects of field operations support, management of OSI equipment, the chain of custody of environmental samples, and the application of specific OSI techniques. The session also included presentations on innovative approaches to support OSI operations, such as the use of remotely operated aerial vehicles and measures to manage software applications during an OSI to ensure the transparency, robustness and availability of mission-critical software.

Sensing Techniques and Signatures

O2.2-029 and P2.2-030 presented a case study for use of the electrical resistivity tomography (ERT) and combined ground magnetic and very low frequency electromagnetic (VLF-EM) geophysical techniques to evaluate the base metal and gold mineralization potential at a site in south-western Nigeria. The presenter used the case study to demonstrate the value of ERT for the detection of relevant OSI observables.

O2.2-199 addressed the potential of unmanned aerial vehicles (UAV) in the context of an OSI. Based on the example of geomagnetic field mapping, the presentation examined the technical capability of UAV platforms and also considered their use with respect to Treaty provisions.

P2.2-036 discussed the potential use of commercial ground penetrating radar (GPR) for OSI applications. Working frequency ranging from 50M Hz to 1 GHz can be customized, thus enabling GPR to meet the practical requirements of OSI scenarios. P2.2-619 presented a method to map radiation using multi-crystal spectrometers to improve spatial precision. The technique uses Monte Carlo generated response functions in an iterative minimization to extract the true underlying radioactivity distribution. The method provides the uncertainties and significance levels of the detection of radioactivity in all areas. P2.2-387 suggested the use of shielded HPGe detectors in field conditions. Transportable shielding has been designed and built, taking into account a balance between transportability and performance of the system.

P2.2-704 used seismometers and vertical electrical sounding penetration tests to study the properties of sediments and produced shear wave velocity maps that could be helpful in seismic micro-zonation of areas where ground motion is considered.

P2.2-313 presented information about radioactive contamination near a tunnel portal at the Semipalatinsk Test Site in Kazakhstan as a consequence of underground nuclear testing. This information contributes to understanding of OSI-relevant observables.

Simulations and Exercises

P2.2-348 focused on the application of a 3-D visualization platform as a tool to support and enhance OSI operation management and decision making. A compact, transportable 3-D simulation platform was proposed. Holographic visualization could also be achieved through holographic goggles to realize immersive visualization. The system could be compatible with standard geographic information system (GIS) platforms.

P2.2-568 presented the status of the airborne simulator. Since airborne operations are a technically demanding aspect of an OSI, the presentation reported on a tool to expedite testing and development of airborne equipment and facilitate training on airborne equipment and procedures in a realistic simulator.

On-Site Inspection Process

P2.2-220 explained the updated concept and organization of the OSI Operations Support Centre as an ad hoc part of the CTBT Operations Centre (COPC). It also illustrated the infrastructure and summarized relevant aspects of the build-up exercise on the launch phase of an OSI (BUE-L) held in November 2019.

P2.2-575 addressed the certification, calibration, maintenance and protection of OSI equipment. To this end, a system has been developed to facilitate the management of OSI equipment at the TeST Centre, which serves headquarters requirements and is also designed for use during an OSI. EIMO, an equipment and instrumentation management system for OSI, was used during BUE-L in November 2019 to generate the equipment list for the OSI mandate.

P2.2-230 focused on the provision of stable and reliable electricity, a critical aspect of field operations support that is essential for a functional OSI. The integration of solar power into the OSI field power distribution was identified as an opportunity to enhance flexibility in the field and harness renewable energy at the base of operations and to deployed field equipment.

P2.2-027 presented the use of radio frequency identification (RFID) for the purpose of environmental sampling for OSI and proposed an approach to potentially address the security and tamper-proofing of OSI samples that could also contribute to chain of custody management for IMS samples.

Communication

O2.2-108 addressed the topic of incorporating appropriate measures to manage software systems during an OSI to ensure the transparency, robustness and availability of mission-critical software. This topic is particularly critical for OSI because the deployed systems are isolated from Internet infrastructure.

P2.2-074 presented a new potential approach to in-field communication during an OSI. It included a study on a compact portable cognitive satellite communication system that could provide an option for OSI communication equipment development.

O2.2 Challenges of On-Site Inspection Abstracts of Oral Presentations

O2.2-029 – Electrical Resistivity Tomography Geophysical Technique for Mapping Base Metal and Gold Mineralization Potential in Iperindo, Ilesha Schist Belt, Southwestern Nigeria

Author: Olawale Osinowo[1]
Co-author: Ahmed Usman[1]
[1]*University of Ibadan, Nigeria*
Corresponding Author: waleosinowo@gmail.com

Electrical Resistivity Tomography (ERT) geophysical technique has been applied in this study to evaluate the base metal and gold mineralization potential of Iperindo in Ilesha Schist Belt, southwestern Nigeria, where commercial exploitation capable of generating revenue and employment for the inhabitants has been challenged by lack of/inadequate subsurface geological/geophysical information. The filtered and inverted electrical resistivity data acquired by occupying five 336 m long E – W trending profiles, established 10 m apart from each other, delineate isolated near-surface but thick (> 30 m) low resistivity zones, especially at the eastern and western ends of the study area. Some of the delineated low resistivity zones (3–200 m) present sharp vertical edges, likely created by vertical faults that flank the zones on both sides. The low resistivity signatures of these zones could be attributed to the occurrence of conductive minerals such as gold and associated base metals which probably exist in pegmatitic veins within the zones. The resistivity/conductivity distribution generated by ERT mapping of spatial distribution of base metal within the subsurface clearly demonstrates the earth imaging strength of geophysics techniques which are applicable for on-site inspection and test ban verification.
Promotional text: The resistivity/conductivity distribution such as generated by ERT mapping of spatial distribution of base metal within the subsurface clearly demonstrates the

earth imaging strength of geophysics techniques which are applicable for on-site inspection and test ban verification.

O2.2-108 – Provisioning and Updating Distributed Software Systems in Network Isolated Environments

Author: Oleksandr Shabelnyk[1]
Co-authors: Christos Tsigkanos[1]; Pantelis Frangoudis[1]
[1]*Technische Universität, Vienna, Austria*
Corresponding Author: oleksandr.shabelnyk@gmail.com

Security constraints of an On-Site Inspection dictate air-gapped isolation of networks, introducing challenges for the reliable provisioning and updating of distributed mission-critical software systems employed during an OSI. Further goals include process transparency and operational robustness, while accommodating domain-specific requirements. To this end, we propose a technical framework addressing the software configuration update in network-isolated environments. Within our comprehensive framework, dependencies are resolved using satisfiability modulo theories, ensuring correctness in terms of version compatibility. The end-to-end system facilitates the update and reconfiguration of isolated on-site systems, while being compatible with container-based software component management as used in practice. We demonstrate the framework over a case study representing a typical scenario.
Promotional text: The paper highlights the importance of appropriate measures to manage software systems during an OSI, ensuring transparency, robustness and availability of mission-critical software.

O2.2-199 – Potential Application of Unmanned Aerial Vehicles for On-Site Inspection

Author: Dmitrii Sagaradze[1]
Co-authors: Artem Dorosev[1]; Igor Markov[1]
[1]*All-Russian Scientific Research Institute Of Technical Physics (VNIITF), Russian Federation*
Corresponding Author: sagaradze.d@gmail.com

In 2018 the 51st Session of Working Group B (WGB-51) of the Provisional Technical Secretariat of the Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO) noted potential applicability of remotely operated vehicles (ROVs) for OSI purposes, but their practical use raises several serious issues that WGB should discuss at its future sessions. Implementation of OSI missions with application of unmanned aerial vehicles (UAV) for aerial multispectral imaging, gamma-radiation monitoring as well as geomagnetic field mapping specified in paragraph 69 Part II of the Protocol would be technically feasible. But at the same it will be necessary to consider legal, technical and organizational issues relating to UAV use for OSI purposes. Based on the example of mostly geomagnetic field mapping technique this paper examines technical capability of UAV application for OSI purposes, its consistency with the Treaty provisions and potential approaches for their resolution.
Promotional text: Based on the example of mostly geomagnetic field mapping technique this paper examines technical capability of UAV application for OSI purposes, its consistency with the Treaty provisions and potential approaches for their resolution.

P2.2 Challenges of On-Site Inspection Abstracts of Poster Presentations

P2.2-027 – Radiation Hardened RFID Solution to OSI Samples Chain of Custody

Author: Peng Li[1]
Co-authors: Lei Han[2]; Xinmin He[1]; Feng Sun[2]; Xue Hang[1]
[1]*Hope Investment Development Corp. Ltd., Beijing, China*
[2]*Wuxi CETC IOT Technology Co. Ltd., China*
Corresponding Author: lipeng1406@163.com

CTBT treaty clarifies that "The DG shall have the primary responsibility for the security, integrity and preservation of samples. The DG shall, in any case, establish a stringent regime governing the collection, handling, transport and analysis of samples". This work is dedicated to the engineering application of IOT/RFID technology to the CTBT technical framework and real OSI scenarios and to provide practical engineering solution. Radiation hardened design was utilized for the first time to develop OSI scenario oriented RFID chips to meet with normal function requirements under nuclear radiation environment while handling OSI samples. Dual-RFID-label mechanism was invented for the first time to realize both tamper evident and Chain-of-Custody solution to OSI samples. Customized containers design of different shapes and materials was also utilized to meet with the requirements of collection, handling, transportation and analysis of all forms of samples including water, soil, vegetation, noble gas. Suggested application solution of global coverage IOT Nano-satellite constellation could be utilized to strengthen the overall Chain-of-Custody concept and in-real-time tracking of OSI samples during transportation and off-site analysis.

Promotional text: This work would fill in the gaps of OSI samples Chain-of-Custody concept. It would contribute to the security and tamper-proof of OSI samples, which could also contribute to the IMS samples COC management.

P2.2-030 – Combined Ground Magnetic and Very Low Frequency Electromagnetic (VLF-EM) Investigations for Gold Exploration Around Ihale in Bunnu-Kabba Area of Kogi, North-Central Nigeria

Author: Olawale Osinowo[1]
[1]*University of Ibadan, Nigeria*
Corresponding Author: waleosinowo@gmail.com

This study combines ground magnetic and Very Low Frequency Electromagnetic (VLF-EM) geophysical investigation techniques to evaluate the economic potential of mineralized pegmatite veins for gold and associated metallic deposits. Twenty five carefully planned magnetic and VLF-EM profiles, each, were occupied east and west of a reference profile purposively established on an identified mineralized pegmatite vein around Ihale in Bunnu – Kabba area of Kogi, north-central Nigeria. The acquired magnetic data were filtered and transformed to remove regional field effect, cultural noise as well as focus magnetic anomaly peaks over corresponding sources. The measured raw real and raw imaginary components of the EM fields were subjected to Fraser and Karous Hjelt filtering to remove harmonic noise, make anomaly amplitudes relate directly to the causative conductors and also generate current density for charactering the subsurface. Seven zones of relatively high current density with matching high residual positive magnetic anomalies present closely correlate-able signatures with subsurface response of the reference profile established where local mining activities indicate evidence of gold and associated metallic mineralization. The applied geophysical techniques in this study demonstrate the efficacy of geophysical tools for delineating natural/induced earth structures and artefacts whose identification are valuable in test ban verification.

Promotional text: Magnetic and VLF Electromagnetic techniques for mapping the occurrence of gold deposits within the subsurface demonstrate the use of geophysical tools for delineating natural/induced earth structures and artefacts whose identification are valuable in test ban verification.

P2.2-036 – Commercially Used Ground Penetrating Radar's Customized Application to OSI

Author: Peng Li[1]
Co-authors: Chunhe Wang[2]; Jinglan Yu[2]; Xinmin He[1]; Cuirong Zhao[2]; Xinghua Shi[2]; Yuan He[1]
[1]*Hope Investment Development Corp. Ltd., Beijing, China*
[2]*China Research Institute of Radio Wave Propagation, Beijing, China*
Corresponding Author: lipeng1406@163.com

According to CTBT treaty, Ground Penetrating Radar (GPR), together with magnetic and gravitational field mapping and electrical conductivity measurements, are non-destructive geophysical detection technology which can achieve effective detection of OSI anomalies or artifacts underground. As a matter of fact, GPRs have been commercially widely used for decades to conduct safety inspection of underground gas pipelines of cities and towns. It has also been commercially widely used to detect caves under the paved roads to avoid any unexpected land subsidence accident. This work is the active result of joint efforts made by experts of OSI and experts of commercial GPR application. Based on the rich experience and data accumulation of underground pipelines and caves detection, customized radar detector design and data processing mechanism suitable for CTBT OSI scenarios has been put forward. According to the requirements of different geological environment, working frequency of radar ranging from 50MHz to 1GHz can be customarily designed, so as to make the GPRs meet with practical requirements of real OSI scenarios. Moreover, the GPRs would be made user-friendly based on Android operating system, with touch screens and blue tooth data communication capability, etc.
Promotional text: This work would bring GPRs' commercial application together with CTBT OSI practical requirements, which could provide another optional choice for OSI essential equipment development.

P2.2-074 – A Compact Portable Cognitive Satellite Communication System for OSI

Author: Peng Li[1]
Co-authors: Peng Chen[2]; Hongzhong Zhao[2]; Xinmin He[1]; Xue Hang[1]; Guohua Zhao[2]
[1]*Hope Investment Development Corp. Ltd., Beijing, China*
[2]*Beijing Hunray Technology Co. Ltd., Beijing, China*
Corresponding Author: lipeng1406@163.com

In principle, OSI could be conducted anywhere on the earth. Communication is mission critical for OSI. 10 years have passed since the last Directed Exercises of OSI communication in Jordan. Some of the communication equipment suggested by the exercise, mostly old fashioned radio communication, would find its restrictions for meeting the practical requirements of OSI. Based on cognitive satellite communication and ad hoc communication networking technologies, this work carried out a study of cognitive satellite communication system for OSI. A compact portable satellite communication prototype VSAT has been developed with high reliable capability achieved by advanced cognitive communication technology. The main specifications are the following: Weight is less than 7 kg including lithium battery, which is suitable for inspectors to carry. Size is 310mm×460mm×60mm with antenna and receiver in an integrated design. Working time is up to 5 hours. Communication speed is up to 256Kbps. By means of working with ad hoc hubs (deployment depending on IA terrains, individual terminals, and commercial encryption, it would provide a reliable communication working environment for IT and IT members, supporting secured communication among IT members, ISP representatives, BoO, CTBTO headquarters and other possible parties.
Promotional text: This work carried out a study on compact portable cognitive satellite communication system for OSI, which would provide an option for OSI communication equipment development, so as to meet the urgent need of OSI communication equipment support requirements.

P2.2-220 – Operations Support Centre During Preparations for an On-Site Inspection

Authors: Julius Kozma[1]; Stian Holen[1]; Gustavo Haquin Gerade[1]; Mario Villagran-Herrera[1]; Franz Ontal[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: julius.kozma@ctbto.org

The Operations Support Centre (OSC) is a crucial element for effective preparation for an on-site inspection (OSI); its organization and proper functioning directly impact the degree of inspection team preparedness before departing for the inspected State Party. The OSC will be activated within a couple of hours after the DG has received a request for an OSI, and it must immediately become operational. That requires a sound concept, a tested organizational approach, adequate infrastructure, clear and user-friendly procedures, and trained staff from all units of the Technical Secretariat. The OSC concept and related operating procedures have evolved over the time. The most recent update reflected the experience from the 2014 integrated field exercise and the commissioning of the new CTBT Operations Centre (COPC) at the PTS headquarters (Ref. SnT2019-T4.4-P13), which is a potential deployment location for an ad hoc OSI OSC at the Vienna International Centre. It was tested during the Build-Up Exercise on the OSI launch phase (BUE-L) in November 2019. This poster explains the updated concept and organization of the OSI OSC as an ad hoc part of the COPC, illustrates the infrastructure, and summarizes relevant aspects of BUE-L.
Promotional text: The poster explains the updated concept and organization of the OSI OSC as an ad hoc part of the COPC, illustrates the infrastructure, and summarizes relevant aspects of BUE-L.

P2.2-230 – OSI Hybrid Power Integration for Base of Operations

Authors: Alana Campbell[1]; Mohamed Ali Nasri[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: alana.catherine.campbell@ctbto.org

One challenge of On-Site Inspection (T2.2) is preparing for deployment to unknown locations with unknown resources. A critical element of a functional Base of Operations is stable and reliable electricity. The current diesel generators and UPS system has been enhanced with a hybrid power system that adds the ability to accept power from other generation sources, such as solar. An increased battery bank allows for more quiet time without the diesel generators reducing fuel usage and CO_2 production. Compact, foldable 100w solar panels have been designed to fit the air transportation containers connecting to inverter hubs that assist the hybrid power unit to supply power to the BOO. Excess energy is stored in battery banks for later use and the design of the system allows for immediate use of solar power anywhere along the distribution network. The smart controller and control screen allow for efficient management of available power, auto-starting generators as a last resort if required. Deployable solar units for smaller field equipment such as samplers or pumps complement smaller fuel generators, and small solar mats and converters that clip directly to existing battery terminals provide trickle charge to remotely deployed field equipment (such as SAMs) during sunlight hours.
Promotional text: Stable and reliable electricity is critical for a functional OSI. The integration of solar power into the OSI field power distribution is an opportunity to enhance flexibility in the field and harness renewable energy at the Base of Operations and to deployed field equipment.

P2.2-313 – Radioactive Signs at Tunnel Portals after Underground Nuclear Tests at Semipalatinsk Test Site

Author: Yurii Dubasov[1]
[1]*Khlopin Radium Institute, St. Petersburg, Russian Federation*
Corresponding Author: yuri.dubasov@gmail.com

One of the possible manners to conduct a clandestine, unannounced underground nuclear explosion may be a test in a tunnel under a mountain. At the Semipalatinsk test site (STS) of the Soviet Union, 209 underground nuclear tests were conducted in the tunnels. Radioactive noble gas (RNG) release of various intensities occurred at ~40% of the tests. In 1996, the Khlopin Radium Institute conducted a survey at the former STS of about 40 tunnels portals before their final closure. The radiation background was measured, gamma spectra were recorded, rock and soil were sampled for radiochemical analyses. The report will present data on contamination of the surveyed tunnel portal areas by radionuclides Cs-137, Sr-90 and others, and compare them with data on the radiation situation during nuclear tests (RNG release). Remaining radioactive traces are the most important sign during on-site inspection.

Promotional text: Report is content the information about radioactive contamination of area near tunnel portal as consequences underground nuclear test. This information is needed for elaboration OSI method.

P2.2-348 – Application of Visualized 3-D Simulation Platform to OSI Operation Management and Decision Making Support

Author: Peng Li[1]
Co-authors: Yongli Zhang[2]; Gang Wu[3]; Xinmin He[1]
[1]*Hope Investment Development Corp. Ltd., Beijing, China*
[2]*Beijing Decent3D Science & Technology Co. Ltd, Beijing, China*
[3]*International Military Cooperation, Ministry of Defense, China*
Corresponding Author: lipeng1406@163.com

An OSI could be conducted anywhere. Due to the concept of the comprehensive nuclear test ban, an OSI inspection area could be in an extremely challenging environment. A simulation platform could be a solution both from the perspective of health and safety and mission efficiency. This work would propose a compact transportable visualized 3-D simulation platform to provide decision making and management support to OSI operations. Based on personal and environmental interactive virtual reality technology, it would quickly create a virtual reality inspection area environment utilizing treaty-agreed commercial remote sensing images and terrain data. Different terrains and environments could be simulated and visualized, such as mountainous areas, the Gobi Desert, water-based areas and inhabited towns under different lighting and weather conditions. The base of operations setup and routine management, health and safety management, contamination area marking, managed access area marking, mission estimation, sub-team daily mission planning, inspection routes planning, search area management, ground inspection and overflight simulation could be achieved. Holographic visualization could also be achieved through holographic goggles to realize immersive visualization. The system is compatible with popular international GIS platforms. During overflight simulations, an external joystick can be used to achieve a more vivid simulation effect. A touch screen has been used for better handling.

Promotional text: This work would propose a commercial compact transportable visualized 3D simulation platform to provide decision making and management support to OSI operations.

P2.2-387 – Improving Environmental Radioactivity Monitoring by the Use of Shielded Portable HPGe Detector

Authors: Antonietta Rizzo[1]; Chiara Telloli[1]; Salvi Stefano[1]; Elena Marrocchino[2]; Carmela Vaccaro[2]; Alberto Ubaldini[1]
[1]*Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Italy*
[2]*University of Ferrara, Italy*
Corresponding Author: antonietta.rizzo@enea.it

The ENEA Traceability Laboratory in Bologna utilizes a portable HPGe gamma spectrometer Trans-SPEC-DX-100T for in situ monitoring campaigns and to evaluate the possible presence of radioisotopes in the environment (e.g. waste assay measurements, emergency response, nuclear safeguards inspection). The instrument is also used in the laboratory to characterize radioisotope concentrations in samples from different sources: ie contaminated environmental soils, food with different radioisotopes absorption rates, nuclear materials. The gamma monitoring technique is allowed to be used during an On-Site Inspection by the Treaty. The specific instrumentation to be used has to be included in the draft list of the equipment for OSI. A good characterization of the monitored site needs the capability to observe a small variation on the activity concentrations and the capacity to lower the background contribution. In order to use the instrument to its full capacity and potential, a transportable shielding has been designed and built-in collaboration with the University of Ferrara, taking into account a good balance between transportability and performance of the system. The results of a monitoring campaign with and without shielding will be shown and the need to include shielding in the draft list of auxiliary equipment will be discussed.

Promotional text: How to cope with mobility and transportability of on-site monitoring and instrumentation performance.

P2.2-568 – Update on the OSI Airborne Techniques Simulator

Authors: Aled Rowlands[1]; Gregor Malich[1]; Mohamed Ali Nasri[1]; Andrew Collinson[1]; Laszlo Kovacs[2]; Gabor Bercesi[2]; Adrienn Bablena[2]; Kornél Szalay[2]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*NAIK Institute of Agricultural Engineering, Gödöllő, Hungary*
Corresponding Authors: aled.prys.rowlands@ctbto.org, kornel.szalay@gmail.com

The development of an airborne physical simulator to support the development and testing of airborne OSI equipment configurations as well as facilitating ground-based training for airborne operations was reported at SnT2019. This paper provides an update to the project, summarises the difficulties of transforming a dilapidated airframe into a multi-purpose structure and describes its commissioning. The interior of an Mi-2 helicopter has been completely transformed and now provides a realistic and flexible configuration enabling simulations of different airframe types. All original cabling and unnecessary elements have been removed while the cockpit, windows and interior lining have been enhanced but still retain the feel of a military helicopter. The exterior of the airframe has been repaired and repainted with hardpoints added to mimic a range of different airframes. These hardpoints allow training on the installation of external equipment such as laser range finders and radar altimeters. Real life scale 3D printed versions of airborne equipment are now available for use in the simulator allowing testing and training on realistic alternatives to the real items.

Promotional text: Airborne operations are a technically demanding aspect of an OSI, this paper reports on a tool to expedite testing and development of airborne equipment and facilitate training on airborne equipment and procedures in a realistic simulator.

P2.2-575 – EIMO: The Equipment and Instrumentation Management System for OSI

Authors: Aled Rowlands[1]; Alicia Lobo[2]; Gregor Malich[1]; Mohamed Ali Nasri[1]; Alana Campbell[1]; Oleksandr Shabelnyk[1]; Nenad Steric[2]; Remi Colbalchini[1]; Peter Labak[3]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Zuehlke Engineering, Vienna, Austria*
[3]*Earth Science Institute, Slovak Academy of Sciences, Bratislava, Slovakia*
Corresponding Author: aled.prys.rowlands@ctbto.org

At SnT 2019 the development of an On-Site Inspection system for managing OSI equipment and software was reported. The system, now called, EIMO – the equipment and instrumentation management system for OSI – has been further expanded and rolled out as a production system. The custom browser-based system is used for recording and tracking both OSI inspection gathering and support equipment. This encompasses the key task of setting maintenance plans and recording all maintenance activities undertaken at an item or system level. EIMO holds definitive information on OSI inspection and support equipment. As well as facilitating work at the TeST Centre, EIMO was also used during the Launch Phase element of the OSI Build-up Exercise in November 2019 to generate the equipment list for the OSI mandate. EIMO has been expanded for use during an OSI. Modified versions of EIMO are available for use at the point of entry to support equipment checking and also in the working and receiving areas at the base of operations to support the management of equipment configurations. EIMO is available to the relevant versions of GIMO to facilitate the planning of missions and field teams as part of the Inspection Team Functionality cycle.

Promotional text: Certifying that OSI equipment has been calibrated, maintained and protected is a fundamental prerequisite of an on-site inspection. To this end a system has been developed to facilitate the management of OSI equipment at the TeST Centre and also during an OSI.

P2.2-619 – Unfolding Directional Aerial Radiation Survey Maps to Enable Extrapolation and Improved Precision

Authors: Laurel Sinclair[1]; Andrew McCann[2]; Patrick Saull[3]; Nathan Murtha[4]; Audrey Macleod[3]
[1]*Canadian Hazards Information Service, Natural Resources Canada*
[2]*Natural Resources Canada, Ottawa, ON, Canada*
[3]*National Research Council, Ottawa, ON, Canada*
[4]*Carleton University, Ottawa, ON, Canada*
Corresponding Author: laurel.sinclair@canada.ca

Gamma spectroscopy measurements are a key component of an on-site inspection conducted under the Comprehensive-Nuclear-Test-Ban-Treaty. Radiometric aerial survey has proven to be an efficient way to cover large areas, however the spatial distributions of features smaller than the survey altitude are smeared out and their radioactivity concentration is underestimated. Moreover, the inspected state party may declare multiple restricted access sites over which the aerial survey may not be able to fly. In previous work presented in this conference series we have shown how multicrystal direction-capable or imaging gamma detectors can reconstruct radioactivity distributions in a restricted access site from vantage points on its perimeter. In this work, we present a new method to unfold the measurement making use of Monte Carlo generated response functions in an iterative minimization to extract the true underlying radioactivity distribution within uncertainties. By requiring the solution be consistent with the measurement from every crystal sub-detector involved in the survey simultaneously, this method greatly improves spatial precision and the distance over which extrapolation is valid. Most importantly, the method provides the significance of the

observation of radioactivity in certain areas, and gives an upper limit on the amount of allowed radioactivity in other areas.
Promotional text: A method to unfold the measurement system response from radioactivity maps made with multi-crystal spectrometers improves spatial precision, permits extrapolation, and determines the significance of the presence of radioactivity in some areas and its absence in others.

P2.2-704 – Geophysical Characterizations of Unconsolidated Sediments for Geotechnical Studies at Bhadrapur Municipality Area of South-East Nepal

Author: Rajendra Prasad Bhandari[1]
Co-authors: Suresh Shrestha[1]; Thakur Kandel[2]; Mukunda Bhattarai[3]; Sulav Kayastha[1]; B. K. Navin[3]
[1]*Department of Mines and Geology (DMG), Kathmandu, Nepal*
[2]*Geoscience Division, Kathmandu, Nepal*
[3]*National Earthquake Monitoring and Research Center, Kathmandu, Nepal*
Corresponding Author: pokhararajendra@gmail.com

Geophysical characterizations of unconsolidated sediments can be correlated with the invasive geotechnical investigations considered as a scientific basis for land use planning and development. In this study, Centerless Circular Array (CCA) having 2 Hz frequency (short period with a circumscribed radius of 2 m) seismometers were used to estimate the subsurface velocity profile, whereas Vertical Electrical Sounding (VES) used to estimate the resistivity of individual layers. Standard Penetration Test (SPT) were used to conduct the field survey for estimating N values. Soil samples were taken for laboratory testing to understand the soil type, water saturation, texture etc. Preliminary result showed that the sediments in Bhadrapur Municipality area which has shear wave (Vs) velocity ranges from 100 to 500 m/s, whereas the resistivity ranges from 20 to 400 ohm-m. Corrected N value for the gravelly sand ranges from 7 to 25 blows whereas for silty sand it ranges from 4 to 10 blows. The shear wave velocity, resistivity and the N value map were prepared. Shear wave velocity and its correlation with N value would be helpful in seismic micro-zonation of the areas where ground motion is considered as an important parameter.
Promotional text: Our department has engaged in using various surface geophysical techniques such as seismic, geoelectric, GPR, geo-magnetics to solve the problems underneath the ground. Those techniques have greater relevance in on-site inspection of the Nuclear Test sites.

T2.3 Seismoacoustic Sources in Theory and Practice

Highlights

Event Screening and Underground Events

O2.3-141 discussed the dependence of the release of shear waves in explosions on the scaled depth of burial. The analysis was based on results from a series of Source Physics Experiments (SPEs) carried out at the Nevada Test Site (USA). Large explosive devices were detonated at different depths in the same borehole. A major goal was to identify sources of "excess" shear, which complicates discrimination criteria. The largest shear wave release occurred at intermediate depths. Activation of pre-existing joints is one possible shear release mechanism that would produce such a distinctive pattern. The results are consistent with SPE near-field records, far-field records and moment tensor inversions and establish the importance of joint unloading at distances of several kilometres from the source. This raises possible implications for nuclear explosion monitoring.

The mb magnitude scale and the mb:Ms criterion are important for event screening. As discussed in P2.3-240, the initial development of the mb magnitude scale (and the mb:Ms criterion) was mainly based on body wave data recorded by standard short-period instruments. Today, the IMS consists of a range of short-period and broadband instruments with a variety of responses.

The presented research aims to improve event screening by enhancing the understanding of variations in mb measurements and determining if current IDC mb measurement methods are optimal. Initial results suggest that variation in instrument response has the potential to affect the consistency of event mb magnitudes using the current IDC mb measurement method. Alternative, potentially more robust methods were considered.

Seismoacoustic Events

O2.3-130 discussed data fusion for the monitoring of seismoacoustic events using data from earthquakes, avalanches, rocket launches, volcanoes and industrial explosions. The monitoring campaign focused on detection of sources at local distances. As some sources are more likely to be detected via seismic signals and others by infrasound signals, the author underlined the importance of co-located seismic and acoustic sensors.

O2.3-070 presented results from the analysis of seismic and infrasound data from IMS and local stations in Israel, including some examples of ground truth seismoacoustic events. The data set comprised infrasound calibration experiments as well as large explosions at the Sayarim shooting range.

P2.3-356 described a prototype waveform cross-correlation based pipeline to identify repeating mining events that match the event definition criteria for the REB. The prototype processes seismic and infrasound data continuously to produce the cross-correlation bulletin (XSEL), which is compared with the automatic bulletin (SEL3) and the REB to improve data processing.

P2.3-079 focused on seismoacoustic signals produced by surface explosions at distances further than what is normally monitored. The aim was to evaluate the use of predictive equations developed for confined explosions, with appropriate adjustments to the coupling coefficients. The United States Bureau of Mines peak particle velocity predictive equation was a good match to the results.

P2.3-116 discussed the discrimination of quarry blasts using seismic and infrasound data in Kazakhstan by applying correlation techniques with a combination of seismic and infrasound data. P2.3-246 analysed accidental explosions in Turkmenistan in 2011 utilizing seismic and infrasound IMS data. The yield for the largest explosion(s) (4–90 tonnes) was determined using the dominant period of these infrasonic signals and was consistent with the yield determined using seismic observations. P2.3-671 focused on improving understanding of the seismoacoustic characteristics of low-yield explosions at near-source distances, with applications to urban seismoacoustic monitoring arrays. Small aperture seismoacoustic arrays were deployed to measure ripple-fire detonations at distances of 3–70 km. Ground truth event details (timing, location, explosive yield) were provided by mine and quarry operators.

P2.3-366 described monitoring explosions at a military training ground in Austria using a mobile infrasound array and seismic sensors. For explosions verified by infrasound data, forward modelling was undertaken to assess the possible release of hypothetical toxic plumes.

P2.3-232 collected the infrasonic signatures of 1001 rocket launches for space missions between 2009 and mid-2020 to provide a referenced data set to support future research on infrasound topics as well as on atmosphere dynamics. Data from IMS stations was analysed to estimate the detectability of rocket infrasound, to evaluate the performance of individual stations, to quantify propagation and attenuation effects and to derive a relation between rocket thrust and acoustic energy.

P2.3-233 and P2.3-286 presented and analysed data from infrasound stations in Costa Rica, including data from diverse events such as volcanic eruptions, fireballs, earthquakes and landslides. It was possible to locate events through back-azimuth triangulation in the region of Central America and the Caribbean. P2.3-376 used tools from NDC in a box (DTK-GPMCC, Geotool and SeisComP3) to locate and analyse data from meteorites, accidental explosions and earthquakes in Iraq. P2.3-423 analysed events detected by the infrasound station IS33 (Madagascar), some of which were associated with sprite and surf events. The analysis was based on data from the World Wide Lightning Location Network and waveform characteristics from DTK-GPMCC.

P2.3-645 and P2.3-647 described earthquake data from the seismic network in Armenia. The seismicity of the Armenian Upland relates to the Arabian-Eurasian plate collision, which is characterized by the diffusive distribution of shallow earthquakes of various magnitudes. Analysis of the focal mechanisms of earthquakes of various magnitudes showed the presence of all fault types.

P2.3-441 highlighted examples from data analysis integrating IMS and IDC data with local seismic data using SEISAN software. Analysis of three events was presented: an earthquake in West Greenland, an earthquake in Denmark and the announced nuclear test by the Democratic People's Republic of Korea on 3 September 2017.

P2.3-415 analysed data from the 2018 eruption and collapse sequence of Kilauea in Hawaii, USA, which resulted in over 70,000 earthquakes (M ≥0) and 54 major earthquakes (M ≥5). Negative isotropic seismic moment tensors were found. The mechanisms of the major earthquakes reveal collapses that are similar to events following nuclear explosions in the Democratic People's Republic of Korea and the Nevada Test Site.

P2.3-708 presents a multi-technology analysis of the 2018 eruption of the Anak Krakatau stratovolcano in Indonesia using data from IMS infrasound and hydroacoustic stations. The eruption triggered the collapse of the south-west flank and summit of the volcano, generating a tsunami that struck Sumatra and Java. The climactic eruption phase was not detected hydroacoustically, but an approximately 12 day swarm of hydroacoustic signals was observed beginning 24 days before the flank collapse event. This study underscores the potential of remote acoustic technology for detecting and characterizing eruptions at submarine or partially submerged volcanoes.

P2.3-591 described an integrated study of seismic and infrasound monitoring for the detection of non-tectonic earthquakes in Indonesia that are caused by volcanic activity. Signals generated by this type of earthquake are dominated by a low frequency and well detected by infrasound technology. P2.3-630 presented the infrasound signals detected at four IMS infrasound stations to document the eruption of Mount Stromboli in Italy in July 2019. The data were processed with DTK-GPMCC and DIVA software.

P2.3-585 and P2.3-372 identified and collected detections of local and regional storms and lightning. Thunder signals were also observed using one-component seismic sensors. It was possible to precisely model the thunder signals for each lightning event and therefore gain some insight into the mechanism of thunder.

Signals from underwater explosions can assist in analysing the details of such incidents, in particular with phenomena such as bubble pulses and reverberation effects. The best known studies to find bubble pulse and propagation effects are spectral analysis and cepstral analysis. P2.3-081 analysed data related to the 2010 sinking of the *ROKS Cheonan* vessel of the Republic of Korea Navy and argued that it was likely caused by a mine explosion.

P2.3-149 presented data from a minequake in Kiruna, Sweden, in 2020. The largest mining-induced earthquake on record in Scandinavia generated signals that were detected at three infrasound stations up to a distance of 300 km. Data from this shallow, moderate-magnitude earthquake provide useful information on ground shaking and local amplification caused by topographical and geological features.

P2.3-504 presented the results of seismoacoustic measurements carried out at Lake Baikal in the Russian Federation in the winter of 2020. A system of six special autonomous geo-hydroacoustic buoys was placed on the ice surface of the lake, forming a seismic array system. Lake depth at the locations of some buoys reached 400 m, and the ice thickness was 1 m. Several local earthquakes were identified on ice seismograms, which allow the study of the energy transformation process from seismic to hydroacoustic and back. In addition, signals generated by a distant 100 tonne seismic vibrator were recorded in deep water under ice conditions. The geo-hydroacoustic buoys demonstrated high reliability in severe winter conditions. The possibility of placing seismic arrays on drifting ice floes in the Arctic for seismoacoustic monitoring can be considered.

O2.3 Seismoacoustic Sources in Theory and Practice Abstracts of Oral Presentations

O2.3-070 – Seismoacoustic Observation of Surface Explosions in Israel Region

Author: Yochai Ben-Horin[1]
[1]*Soreq Nuclear Research Center, Yavne, Israel*
Corresponding Author: yochai.benhorin@gmail.com

The International Data Center (IDC) analyze routinely seismoacoustic data for producing a list of seismoacoustic events as part of the Comprehensive Nuclear-Test Ban Treaty (CTBT) verification regime. However, the fusion between seismic and infrasound data is not yet satisfactory. A set of seismoacoustic events with known location, origin time and if possible their energy, is necessary in order to improve our understanding, and to calibrate our algorithms and stations. Sayarim shooting range is located at the south of Israel, it hosted several sets of dedicated calibration explosions during summer 2009 and winter 2011. In addition several times per year, large explosions of the order of 20-40 ton, are detonated at the range. Some of the explosions were detected by the IMS infrasound stations. In this work, we present the results of seismic and infrasound analysis of these explosions based on data from IMS stations and local stations.
Promotional text: In this work, we present the results of seismic and infrasound analysis of explosions, in Israel, based on data from IMS stations and local stations.

O2.3-130 – Seismoacoustic Data Fusion: Determining the Best Acquisition Designs for Multi-Phenomenological Monitoring Campaigns

Authors: Sarah Albert[1]; Elizabeth Berg[1]; Ronald Brogan[2]
[1]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
[2]*ENSCO, Inc. Springfield, VA, USA*
Corresponding Author: salber@sandia.gov

For low-yield monitoring applications, the combined analysis of seismic and infrasound data could lead to significant improvements in our understanding of the processes that simultaneously generate both types of signals. Assembling datasets that contain seismic and infrasound signals generated by a single source can provide a better understanding of specific source processes. The successful combination of signals requires understanding the fidelity of infrasound measurements – especially for local, temporary instrumentation. Therefore, the first part of this presentation will focus on understanding and constructing methods by which the quality of infrasound data can be enhanced to match that of seismic data. Then, we present an in-depth analysis on the current state of seismo-acoustic data fusion and examine its use in monitoring applications. This presentation will cover a series of seismo-acoustic datasets that contain signals generated by a variety of source processes, including earthquake sequences, avalanche/landslide signals, rocket

launches, and industrial explosions. We also present findings from joint analyses of these datasets to examine the unique properties of each source type. Ultimately, we determine the best acquisition designs for multiphenomenological monitoring campaigns with a focus on seismo-acoustic data fusion.
Promotional text: The presentation supports the conference goal to identify opportunities and methods for improving nuclear test monitoring and verification. Evaluating acquisition designs for multiphenomenological monitoring campaigns leads to a better understanding of source processes.

O2.3-141 – Correlating Shear Content in Seismic Source Functions to Scaled Depth of Burial for a Series of Buried Chemical Explosions

Author: David Steedman[1]
Co-authors: Christopher Bradley[1]; Michael Cleveland[1]; Ryan Modrak[1]
[1]*Los Alamos National Laboratory (LANL), Los Alamos, NM, USA*
Corresponding Authors: rmodrak@lanl.gov, dwsteed@lanl.gov

We have previously used data from the Source Physics Experiment (SPE) to relate evidence of joint slip in the near field to the yield-scaled depth-of-burial (SDOB) of buried chemical explosions in granite. A sudden surge in tangential velocity occurs in velocity records just after the passage of the peak radial shock for moderately overburied tests. This surge does not appear for nominal SDOB tests or for the "over-buried" Green's function test. Further, we related this phenomenon to the estimated range of declared Democratic People's Republic of Korea tests in granite and the likelihood of those tests to confuse MS:mb earthquake/explosion discrimination methods. To render these results practical for monitoring we studied SPE seismic data to identify a SDOB effect. Through constraining the known SPE test parameters (e.g., hypocenter, velocity model) we perform a suite of source inversions with varying tensor source components. Goodness-of-fit trends between recorded seismic data and synthetic waveforms identify the source parameters, such as unexpectedly large shear contributions, that give rise to the observed tangential response in the near field. The results provide an indication that near-field joint release can contribute to the far-field waveforms as excess shear energy.
Promotional text: This work supports the objective of improving nuclear test monitoring and verification by using chemical explosion test data to develop a geomechanical model to explain production in the near-source regime of unexpected shear content seen in the seismic monitoring regime.

P2.3 Seismoacoustic Sources in Theory and Practice Abstracts of Poster Presentations

P2.3-079 – Air and Ground Vibrations from Explosions on the Earth's Surface

Author: Michelle Grobbelaar[1]
[1]*Council for Geoscience, Pretoria, South Africa*
Corresponding Author: michelle@geoscience.org.za

Most equations used to predict the ground motion produced by explosions were developed using confined blasts that were detonated with the intention of breaking rock for mining or tunnelling. Ground motion is usually recorded by geophones or seismometers. The air blast produced by openpit blasts and explosions on the surface can pose a significant risk, thus microphones and pressure gauges are often also used to monitor the effects of the explosion. The aim is to determine whether or not the predictive equations developed for confined explosions can be used to predict the effects from explosions placed on the surface, with appropriate adjustments to the various coefficients. Three predictive equations developed for buried explosions were tested and it was shown that the United States Bureau of Mines peak particle velocity (PPV) predictive equation is the most reliable. In addition, a predictive equation using the secondary atmospheric shock wave phenomenon also produced good results and is easier to measure. These equations may be utilised both for demolition sites, where old and potentially unstable explosives and obsolete equipment are destroyed on the surface of the ground, and for assisting in forensic seismology to determine the details of an unexpected and unknown explosion.

Promotional text: The study focused on seismoacoustic signals produced by surface explosions at distances further than what is normally monitored. Although the explosions were not on the same scale as those monitored by the IMS, the study provides interesting insight into forensic seismology.

P2.3-081 – Characteristics Review for Underwater Explosions Based on Depth and Source Types

Author: So Gu Kim[1]
[1]*Korea Seismological Institute, Republic of Korea*
Corresponding Author: sogukim@hanmail.net

Most of underwater explosions show characteristics of bubble pulse and reverberation effects. Therefore it is most important to find these two phenomena in order to identify an underwater explosion for any sinking and/or missing a ship or a submarine. The best known studies to find bubble pulse and propagation effects are spectral analysis and cepstral analysis. The review technologies for underwater explosion includes Kursk submarine disaster, ARA San Juan Missing, some Russian underwater nuclear explosion as well as the ROKS Cheonan Sinking which is the main topic in this study. Seismologically it is also the most important to find a positive polarity of the first P-wave arrival from the vertical component record whether or not it is an underwater explosion. Nonetheless it is not always clear to find the upward (compression) of the first P-wave onsets in case of an underwater explosion inside a submarine. This paper is stressed on a shallow underwater explosion near the surface like the ROKS Cheonan Sinking showing a bubble jet characteristic resulting in splitting the ship into two pieces. The phenomena of a bubble jet and a toroidal bubble are highlighted in high resolution spectral analysis for a shallow underwater explosion.

P2.3-116 – Discrimination of Quarry Blasts Using a Complex of Seismic and Infrasound Data in Kazakhstan

Authors: Alexandr Smirnov[1]; Natalia Mikhailova[1]; Aidyn Mukambaev[1]
[1]*Institute of Geophysical Research, Almaty, Kazakhstan*
Corresponding Author: infra.smirnoff@gmail.com

The monitoring system of NNC RoK comprises five seismic arrays, eight 3-component stations, and three infrasound arrays. Every year, the network in Central Asia registers and processes some 20,000 seismic events. Among the total bulk of such processed events, about 5,000 events are blasts of different characters. Mainly, they are industrial quarry blasts. The technique has been developed and technology has been generated for recognition of the character of the event based on the set of seismic and infrasound data, which can also increase the accuracy of blast localization significantly on account of reliable reference to the specific quarry. For twelve quarries, template seismic waveforms have been produced. It has been shown that a record of the Lg phase at every quarry at a specific station has a specific form; notably, record forms of this phase from different blasts registered by the same station at the same component for the same quarry are very similar. This feature is used as a criterion for recognition. This technique has been tested with data from the Aqbastau quarry. The findings of this research proved that this method is feasible and highly efficient.

Promotional text: Discrimination of quarry blasts applying correlation techniques with a combination of seismic and infrasound data can support national needs, and to improve nuclear test monitoring and verification.

P2.3-149 – Seismoacoustic Analysis of Mw 4.2 Mining Induced Earthquake Nearby Kiruna, Sweden

Authors: Antoine L. Turquet[1]; Quentin Brissaud[1]; Johan Kero[2]; Sven Peter Näsholm[1]; Tormod Kværna[1]; Alexis LePichon[3]; Constantino Listowski[3]
[1]*Norwegian Seismic Array (NORSAR), Kjeller, Norway*
[2]*Swedish Institute of Space Physics, Kiruna, Sweden*
[3]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: antoine@norsar.no

An earthquake happened in 18 May 2020 early morning in the Kiruna underground iron ore mine (Northern Sweden) having a magnitude Mw 4.2. Following the earthquake, the mine was immediately evacuated because of the risk of aftershocks. This event is the largest mining-induced earthquake that has ever taken place in Scandinavia and it produced signals recorded by three infrasound arrays at distances of 7 km (KRIS, Sweden), 155 km (IS37, Norway) and 286 km (ARCI, Norway). We explore seismo-acoustic features of this event recorded in near and far-field focusing on how the signal propagated in the atmosphere and in the solid earth. Our study provides a detailed comparison between observed and predicted wave front characteristics at the arrays. We also conduct a comparison of amplitude corrected for propagation effect versus magnitude and ground shaking amplitude. These results show that infrasound recorded up to ~300 km from a shallow moderate-magnitude earthquake can provide ground shaking information as well as local amplification caused by topographic and geological features.

Promotional text: Infrasound waves are inaudible low frequency sound waves that can be generated during earthquakes. A minequake happened in Kiruna generated infrasound and recorded up to 300 km distance. We investigate waves from different stations and explore what has happened during this quake.

P2.3-232 – Infrasonic Signatures of 1001 Rocket Launches for Space Missions

Authors: Peter Gaebler[1]; Christoph Pilger[1]; Patrick Hupe[1]; Lars Ceranna[1]
[1]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
Corresponding Author: peter.gaebler@bgr.de

In the present study we analyze infrasound signatures of 1001 rocket launches for space missions recorded at stations of the International Monitoring System between 2009 and mid-2020. We include all surface- or ocean-based launches within this period with known launch time, location, rocket type, and mission name; whereas launches of sounding rockets and ballistic missiles for scientific and military purposes, respectively, are excluded from our study. We characterize the infrasonic signatures of over 70 different types of rockets launched at 27 different globally distributed spaceports to estimate the general detectability of rocket infrasound, to evaluate the individual station performance, to quantify propagation and attenuation effects and, finally, to derive a relation between rocket thrust and acoustic energy. Results from the infrasound analysis of the launches will be provided as a DOI referenced dataset for supporting future research on infrasound topics as well as on atmospheric dynamics.

Promotional text: Infrasonic signatures of 1001 rocket launches for space missions are analyzed to provide a DOI referenced dataset to support future research on infrasound topics as well as on atmosphere dynamics.

P2.3-233 – Infrasound at Costa Rica

Authors: Ronnie Quintero[1]; Daniela Campos[1]; Hairo Villalobos[1]
[1]*Observatorio Vulcanologico y Sismologico de Costa Rica (OVSICORI), Costa Rica*
Corresponding Author: rquinter@una.cr

The NDC-CR has promoted the use of the infrasound methodology in Costa Rica and in the LAC region with the installation of permanent (IVTCR) and temporary (I069CR) stations in the country, as well as with the organization of regional workshop in the field (Infrasound workshop 2019 jointly by CTBTO and NDC-CR). The I069CR and IVTCR identified different infrasound sources. Among the most relevant is the fall of the Agua Zarcas meteorite in Central Costa Rica, on April 23, 2019, 21:07 local time, meteorite from which more than 30 kg were recovered by locals and which has had a great impact on the national and international scientific community. OVSICORI-UNA permanent stations have recorded specific events; for example, the landslide of ~25e+06 m^3 on August 26, 2020, 04:00 am local time on the Irazú volcano; recorded by JTS (AS025), which is located ~125km from the source. Although infrasound instrument had been operating since 2007 at the JTS site and the OVSICORIUNA seismic network had installed instruments near volcanic sources, it is until recently that the community had shown interest in this methodology and the CTBTO jointly with the NDC-LAC could play an important role to build capacity in the field.
Promotional text: Temporary and permanent infrasound stations had been installed by OVSICORi- UNA (NDC-CR) to characterized acoustic source in the zone, with great impact to help in the determination of volcano explosions. Data also used to study meteorite fall in April 23, 2019.

P2.3-240 – Understanding mb Variations: The Implications of a Global IMS

Authors: Jessica Keeble[1]; Neil Selby[1]
[1]*AWE Blacknest, Reading, United Kingdom*
Corresponding Author: jess@blacknest.gov.uk

When complete, the International Monitoring System (IMS) will include 170 seismometer stations. These stations consist of various seismometer types, and are located in a range of geological and tectonic settings. The data recorded can be used to determine the body-wave magnitude (mb) of a seismic event, which is used in the mb:Ms event screening criterion applied at the International Data Centre (IDC). Event screening being the rejection of the null hypothesis that an event is a single point underground explosion. Initial development of the mb magnitude scale (and the mb:Ms criterion) was mainly based on body-wave data recorded by standard short-period instruments. Today, the IMS consists of a range of short-period and broadband instruments with a variety of responses. Our work seeks to understand the implications of varying instrumentation and the potential impact on the mb values measured, as well as investigating the effect of variations in attenuation. Initial results suggest that a combination of these variables has the potential to affect the consistency of event mb magnitudes using the current IDC mb measurement method. We consider alternative methods which could prove more robust. UK Ministry of Defence © Crown Owned Copyright 2020/AWE.
Promotional text: This research aims to improve event screening by enhancing our understanding of variations in mb measurements and determining if current IDC mb measurement methods are optimal.

P2.3-246 – The 7 July 2011 Abadan, Turkmenistan, Explosions: A Seismoacoustic Analysis

Authors: Stuart Nippress[1]; Alexandra Nippress[1]; David Green[1]
[1]*AWE Blacknest, Reading, United Kingdom*
Corresponding Author: stuart@blacknest.gov.uk

At 11:40 (UTC) on 7th July 2011, a series of accidental explosions occurred in the town of Abadan, Turkmenistan. The Turkmenistan government listed the cause of the accident as the ignition of pyrotechnic matter intended for fireworks, which then spread to military storage areas, where an estimated 5,000–50,000 tons of ammunition was stored (Boggs et al., 2013). The explosions are clearly observed ~11 km away at the International Monitoring System (IMS) seismometer array GEYT (Turkmenistan). A total of 30 individual events can be identified. Yields are estimated using P-wave (Koper et al., 2002) and Rg amplitude (Bonner and Russell, 2013) and range between 0.5–45 tonnes (TNT equivalent). IMS infrasound arrays in Kazakhstan, Russia, and Germany observed these explosions. A yield for the largest explosion(s) (4–90 tonnes) is determined using the dominant period of these infrasonic signals (Whitaker, 2006), and is consistent with the yield determined using seismic observations. Air-to-ground coupled waves at GEYT exhibit downward first motions, consistent with an initial positive blast overpressure. We measure the period and peak-to-peak amplitude of the air-to-ground coupled waves and find amplitude varies with yield but not period. UK Ministry of Defence © Crown Owned Copyright 2020/AWE.
Promotional text: We analyse the 7th July 2011 Abadan, Turkmenistan accidental explosions through utilising both seismic and infrasound IMS data. UK Ministry of Defence © Crown Owned Copyright 2020/AWE

P2.3-286 – Infrasound Bulletin from Local and Regional Sources by the NDC of Costa Rica Between 2018 and 2020 and Integration of Data from I20EC, I51GB, I08BR, I09BR (IMS) Infrasound Stations with Local Volcanic Infrasound Monitoring Networks and Portable Array I69CR (CTBTO)

Author: Hairo Villalobos[1]
Co-authors: Ronnie Quintero[1]; Daniela Campos[1]
[1]*Observatorio Vulcanologico y Sismologico de Costa Rica (OVSICORI), Costa Rica*
Corresponding Author: hairo.villalobos.villalobos@una.cr

Since 2018, the inclusion of infrasound monitoring in active volcanoes in Costa Rica with local networks has been implemented by OVSICORI-UNA. In addition, at the end of 2018, two portable infrasound arrays were installed, such as I69CR and IVTCR in cooperation with CTBTO and UNIFI. The NDC-CR includes the integration of IMS stations such as I20EC, I51GB, I08BR, I09BR, thus making it possible to use the event location option through back-azimuth triangulation for relevant local and regional events in the region of Central America and the Caribbean. Among the relevant events from local and regional infrasound sources analyzed for the Infrasound bulletin are the following. Volcanic events: small volcanic explosions (Rincón de la Vieja Volcano, Turrialba Volcano, Poas Volcano between 2018 and 2020). Events of fireballs or meteorites detected in the I69CR portable station and IMS stations: Fireball over Bering Sea 2018-12-18, Cuba Meteorite 2019-02-01, Haiti Meteorite 2019-04-14, Costa Rica Aguas Zarcas Meteorite 2019-04-24, Meteorite South East New Orleans 2019- 05-04, Fireball over Caribbean South Puerto Rico 2019-06-22, Meteorite North Puerto Rico 2020-01-17. Seismic events: Earthquake between Costa Rica and Panama of 2019-06-26. Irazú Volcano landslide event August 26, 2020.
Promotional text: With this infrasound bulletin, it is possible to have a characterization and knowledge of the different sources of infrasound in the Central American and Caribbean region.

P2.3-356 – Finding Repeating Mining Events Using Waveform Cross-Correlation at Seismic and Infrasound IMS Stations

Author: Ivan Kitov[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: ivan.kitov@ctbto.org

Mine blasts are an example of repeating seismic/infrasound events with very close epicenters. In some areas, hundreds of mining blasts per year are measured by the IMS and built by the IDC. Waveform cross-correlation is a natural method to detect repeating signals. The IDC has been testing a prototype WCC-based pipeline to find repeating mining events matching the event definition criteria (EDC) for the Reviewed Event Bulletin (REB). The REB is used as a source of master events with seismic and infrasound waveform templates. Several open-pit mines create intensive acoustic waves detected by the IMS infrasound network and these detections are used to build seismic-infrasound events matching the EDC. The prototype pipeline is processing seismic and infrasound data continuously and we systematically compare the cross-correlation bulletin (XSEL) with the automatic bulletin (SEL3) and the REB. This comparison is used to tune the defining parameters of data processing. Here, we present the overall statistics of the continuous processing in the first half of 2021 and the results of offline testing of several mines in Eurasia and USA and two specific time intervals.
Promotional text: Waveform cross-correlation is a natural method to detect repeating signals. Mine blasts are an example of repeating seismic/infrasound events with very close epicenters. In some areas, hundreds of mining blasts per year are measured by the IMS and built by the IDC.

P2.3-366 – Near Ground Explosion: Monitoring with a Mobile Infrasound Array and Seismic Sensors

Authors: Ulrike Mitterbauer[1]; Maria-Theresia Apoloner[1]; Peter Mohr[2]; Kathrin Baumann-Stanzer[1]; Alexander Hieden[1]
[1]*Central Institution for Meteorology and Geodynamics (ZAMG), Vienna, Austria*
[2]*Ministry of Defence, Vienna, Austria*
Corresponding Author: ulrike.mitterbauer@zamg.ac.at

The project ABC-MAUS is a collaboration between the Austrian Ministry of Defense, Joanneum Research, the Austrian national weather and geophysical service Zentralanstalt für Meteorologie und Geodynamik (ZAMG), including the Austrian National Data Center (NDC), as well as the private company GIHMM. The aim is to develop a strategy of protection for chemical, biological, radiological and nuclear threads (CBRN) for the Austrian armed forces. In the frame of the project, a mobile infrasound array was deployed together with seismic sensors to monitor the military training ground Allentsteig in Lower Austria. During one week a series of controlled explosions, originating from different sources, was recorded. The Austrian NDC developed a tabletop exercise based on a hypothetical explosion. The collected waveform data was analyzed and used to locate the explosion. Once the explosion had been verified by infrasound data, forward modeling assuming a hazardous release was undertaken to understand which areas might have been affected by a resulting toxic plume (reference to contribution by Hieden et al.).
Promotional text: In the frame of the project, a mobile infrasound array was deployed together with seismic sensors to monitor the military training ground Allentsteig in Lower Austria. During one week a series of controlled explosions, originating from different sources, was recorded.

P2.3-372 – ThunderSeis: Seismic Analysis of Thunder Signals Recorded at the Gaisberg Mountain, Austria

Authors: Artemii Novoselov[1]; Florian Fuchs[1]; Manfred Dorninger[1]; Götz Bokelmann[1]
[1]*University of Vienna, Vienna, Austria*
Corresponding Author: artemii.novoselov@univie.ac.at

Lightning strokes create powerful wavefields of seismoacoustic nature, which we refer to as thunder. Unfortunately, even though bolts of lightning received much attention in such fields as physics of plasma and meteorology, less research was conducted to investigate the thunder itself. A radio tower on the top of the Gaisberg mountain in Salzburg is permanently instrumented with electrical sensors able to record the current of lightning strokes hitting the tower's top. In October 2020, observations of 5 thunder signals have been made using several one-component seismic sensors. At the same time, this tower is instrumented with a meteorological station, which allows us to model precisely the propagation of seismo-acoustic thunder signals from the above-mentioned lightnings. These observations and modeling give insight into how thunder is created during the lightning stroke, which is an important milestone for seismo-acoustic observations of atmospheric events.

Promotional text: We measure the seismic signal as well as electrical parameters produced by the lightning. We were able to model precisely such thunder signals for each lightning event and therefore were able to gain some insights into the mechanism of thunder.

P2.3-376 – Bulletin of Iraqi NDC Events Analysis

Author: Yasameen Hameed Shamkhi[1]
[1]*Iraqi National Monitoring Authority, Iraq*
Corresponding Author: yasmin_hameed32@yahoo.com

Through the International Monitoring System (IMS) of the Comprehensive Nuclear Test Ban Treaty (CTBT) and through their continuous work despite COVID-19, we still benefit from IMS data and the International Data Center (IDC) products. We analyzed many events that occurred and detected via infrasound stations. As the meteor in Turkey on 27 May 2020 which was analyzed with software DTK-(G)PMCC and located with the Geotool and compared results with the catalog reference of analyzed events of NASA. As well as the explosion that occurred in Russia near Achinsk on 5 August 2019, which generated intense infrasound signals including both seismic and acoustic arrivals from infrasound and seismic stations of IMS, and also took the opportunity to analyze and locate event via both the DTK-(G)PMCC and the Geotool. Through SeisComp3 software already installed in our Iraqi NDC an acquisition system to process the real-time data. We will display an earthquake that occurred On 3 June 2020 at the Iraq-Iran border, which was monitored by the Iraqi seismic stations and detected by SeisComp3 and our local stations not belonging to IMS stations and Geotool for analysis and comparing results.

Promotional text: Analysis of seismo-acoustic data for IMS by NDC Iraq using NDC in a box tools.

P2.3-415 – Negative Isotropic Seismic Moment Tensors, Migrating and Cyclic Seismicity During the 2018 Summit Collapse at Kilauea Caldera

Author: Celso Alvizuri[1]
Co-authors: Robin Matoza[2]; Paul Okubo[3]
[1]*University of Lausanne, Switzerland*
[2]*University of California, Santa Barbara, CA, USA*
[3]*University of Hawai'i at Mānoa, HI, USA*
Corresponding Author: celso.alvizuri@unil.ch

The 2018 rift zone eruption of Kilauea volcano was accompanied by a remarkable and episodic collapse of its summit. Between May-August the eruption and collapse sequence included over 70,000 earthquakes (M≥0) and 54 major earthquakes (M≥5). We analyzed the seismicity in the Kilauea summit region and estimated seismic full moment tensors with their uncertainties for the 54 M≥5 events. These events occurred at almost daily intervals and were accompanied by intense seismicity which was concentrated between 0-3 km depths beneath the Halema'uma'u pit crater. The hypocenters reveal partial elliptical patterns (map view) that migrated downward by ~200 m. The moment tensors reveal remarkably consistent mechanisms, with negative isotropic source types and localized uncertainties, and vertical P-axis orientations. From the moment tensors we derived Poisson's ratios which are variable (v=0.1–0.3) for the first half of the collapse events and converged to v~0.28 from June 26 onward.

Promotional text: We analyzed 54 earthquakes from the 2018 eruption at Kilauea caldera. Their mechanisms reveal collapses similar to events following nuclear explosions in North Korea and the Nevada Test Site. The mechanisms at Kilauea appear related to evacuation-collapse of its magma reservoir.

P2.3-423 – High Frequency Events Detected by IS33

Author: Tahina Rakotoarisoa[1]
Co-authors: Andry Ramanantsoa[1]; Jean Bernardo Andrianaivoarisoa[1]; Fanomezana Randrianarinosy[1]; Sandra Razafimamonjy[1]; Gerard Rambolamanana[2]
[1]*Institute and Observatory of Geophysics of Antananarivo (IOGA), Madagascar*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: tahinarisoa@gmail.com

High Frequency infrasound are produced generally by explosion, aircraft, storm or lightning…(Campus and Christie, 2010). High frequency infrasound signals are detected by I33MG at the azimuth around 39°. To perform the study, IMS infrasound data from I33MG and I19DJ are processed by mean of PMCC method. After investigation these events are correlated with oceanic storms in the Indian Ocean. In this area, lightning flashes, halo and sprite happen frequently (Christian et al., 2003, Chen et al., 2008) as well as surf events. These events are located at far as 3000 km from I33MG. Frequency of I33MG detections are less than 4 Hz and less than 2 Hz for I19DJ detections. Sources of these events would be strong for having high frequency signal detected for a long distance.

Promotional text: Characterize unknown events in order to better identify potential CTBTO relevant event and enhance infrasound station detectability.

P2.3-441 – Examples from Data Analysis Integrating IMS/IDC Data with Local Seismic Data in SEISAN

Author: Tine B. Larsen[1]
Co-authors: Peter Henrik Voss[1]; Trine Dahl-Jensen[1]; Lars Ottemöller[2]; Jens Havskov[2]
[1]*Geological Survey of Denmark and Greenland (GEUS), Denmark*
[2]*University of Bergen, Norway*
Corresponding Author: tbl@geus.dk

We demonstrate here the advantages of combining data from local seismographs with IMS data in the analysis of both local and distant events. The implementation of new IMS to SEISAN and IDC to SEISAN links makes the integration much easier than before. These links are the results of a project funded by the EU (CELEX 02018D0298-20200423) to facilitate the use of IMS and IDC data at NDCs using the SEISAN package for routine seismic analysis. In this presentation we show how to import parametric data in Nordic format and waveform data in SEED format for a combined analysis of three events: a) an earthquake in West Greenland on 2020-09-27. The regional seismograph network in Greenland is very sparse, and the addition of extra data is extremely valuable. b) an earthquake in Denmark on 2018-09-16 where distant phases can add extra information about the event, and finally c) the DPRK nuclear test on 2017-09-03 which was recorded on both seismographs in Denmark and Greenland. All three events are relocated using the data integration.

Promotional text: Demonstrate how the new SEISAN link can improve the ability of NDCs to use IMS/IDC data and participate in verification.

P2.3-504 – Seismoacoustic Observations Using a Seismic Array on an Ice Floe

Authors: Alexey Sobisevich[1]; Dmitriy Presnov[1]; Daniil Zagorskiy[1]; Artem Numalov[1]
[1]*Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, Russian Federation*
Corresponding Author: presnov@physics.msu.ru

We present the results of seismoacoustic wavefield geophysical measurements carried out at Lake Baikal in the winter of 2020. A system of six special autonomous geo-hydroacoustic buoys, capable of continuously functioning at least for a week, was used as measuring equipment. Each individual buoy consists of a recording system, a seismometer-velocimeter, a hydrophone and wireless data transmission facilities. The measuring system was placed on an ice surface of the lake, forming a seismic antenna system. Lake depth at the locations of some buoys reached 400 m, the ice thickness was 1 m. As a result of experimental data processing, the arrival times of several local earthquakes were identified on ice seismograms. This allows one to study the process of seismic energy transformation into hydroacoustic and back. In addition, a hydroacoustic signal generated by the operation of a distant 100-ton seismic vibrator was recorded in deep water under ice conditions. It can be concluded that geohydroacoustic buoys have demonstrated the convenience and high reliability of use in severe winter conditions. Thus, the possibility of placing seismic arrays on drifting ice floes in the Arctic for solving problems of seismoacoustic monitoring can be considered confirmed.

Promotional text: The possibility of application ice monted seismic arrays for seismoacostic monitoring is demonstrated.

P2.3-585 – Identifying and Tracking Regional Storms with Infrasound Data

Author: Marcell Pasztor[1]
Co-authors: Csenge Czanik[2]; Tereza Sindelarova[3]; Jaroslav Chum[3]; Istvan Bondar[2]
[1]*Eotvos Lorand University, Hungary*
[2]*Research Centre for Astronomy and Earth Sciences, Budapest, Hungary*
[3]*Czech Academy of Sciences, Institute of Atmospheric Physics, Prague, Czech Republic*
Corresponding Author: pasztorms@gmail.com

The infrasound array at Piszkés-tető, Hungary (PSZI) has been operational since May, 2017. Since then PSZI has collected hundreds of thousands detections. These include detections both from known and unknown sources. The categorization of the detections would be important for future automation. The objective of this study is to identify and collect those detections that belong to local and regional storms and lightnings. We present a methodology to identify storms by correlating lightning data from the Blitzortung database we consider as ground truth with the PMCC infrasound detections at PSZI. We also analyze the seasonal variations in the directions and distances of the detected storms.

Promotional text: We build a ground truth database of regional storms and lighting detected by the PSZI infrasound array that in the future allow us to apply machine learning technologies for the automatic screening of storms and lightnings in infrasound records.

P2.3-591 – An Integrated Study of Seismic and Infrasound for Detecting Non-Tectonic Earthquakes in Indonesia

Authors: Aldilla Damayanti Purnama Ratri[1]; Yusuf Hadi Perdana[1]
[1]*Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), Jakarta, Indonesia*
Corresponding Author: aldilla.damayanti16@gmail.com

Indonesia is in an earthquake prone area, not only tectonic earthquakes but also non-tectonic earthquakes. Non-tectonic earthquakes are unique, because they rarely happen. However, in the last decade there have been many non-tectonic earthquakes recorded by seismic sensors due to volcanic activity. Therefore, we need to validate the earthquakes, whether they are caused by tectonic or non-tectonic activity. To distinguish between these earthquakes, we need to integrate parameters between seismic and non-seismic (infrasound) measurement. Tectonic and non-tectonic earthquakes have different frequencies. Non-tectonic earthquakes are dominated by a low frequency and well detected by infrasound measurement, because Infrasound is an acoustic wave with very low frequency less than 20 Hz (~0.01 – 20 Hz).

Promotional text: Seismic and non-seismic (Infrasound) measurement is a good combination to detect and validate non-tectonic earthquake. By studying these parameters, we want to learn specific characteristic of non-tectonic earthquake to give early warning to the society.

P2.3-630 – Stromboli Volcano Eruption 2019-07-03 and Atmospheric Influence on the Detection Capability on the Infrasound Stations

Authors: Abdelouaheb Agrebi[1]; Andry Ramanantsoa[2]; Gerard Rambolamanana[1]; Eddy Harilala Rasolomanana[3]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Institute and Observatory of Geophysics of Antananarivo (IOGA), Madagascar*
[3]*Université d'Antananarivo, Ecole Polytechnique, Antananarivo, Madagascar*
Corresponding Author: abdelouaheb.agrebi@ctbto.org

The International Monitoring System (IMS) is part of the verification regime of the CTBT; in addition, civil and scientific applications are a possible additional benefit that State Signatories could gain from participation in the Treaty verification regime. One of the four technologies used in the IMS is the infrasound network composed of 60 array stations when the network is complete and which is effective for tracking and quantifying volcano eruptions phenomena. In this paper we will focus on one of the most violent eruptions of Stromboli volcano which is one of the most active volcanoes in Italy and on the earth, occurred on 03 July 2019 using data from four IMS Infrasound stations situated in different distance from the Stromboli volcano to observe the detection capability of the Infrasound network in the IMS and the influemce of zonal wind on the infrasound stations detectability as the infrasound propagate in different layer of the atmosphere and depends also on the wind field. The analysis of infrasonic pressure waves generated by Stromboli volcano is essential to the understanding of volcanic explosion. DTK_GPMCC and DIVA software are used to perform this study (Cansi, 1995; Le Pichon, Matoza, Brachet and Cansi, 2010).

Promotional text: A study of a violent eruptions of Stromboli volcano, occurred on 03_07_2019 using data from four IMS Infrasound stations situated in different distance from Stromboli volcano to observe the detection capability of the IMS Infrasound station and the influence of the atmosphere.

P2.3-645 – Armenian Seismic Network and Earthquake Catalogue

Author: Sos Margaryan[1]
Co-authors: Yoann Cano[2]; Corentin Quedec[2]
[1]*Armenian National Survey for Seismic Protection (NSSP), Armenia*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: msos78@hotmail.com

Seismic networks are a source of valuable data for seismological research. For a few years in cooperation with the French CEA/DASE broadband seismic network in Armenia has been upgraded. Among various tasks in seismological research, the modern network allows improving the quality of the catalog. The seismicity of the Armenian Upland relates to the Arabian-Eurasian plate collision, which is characterized by the diffusive distribution of shallow earthquakes of various magnitudes. The strong shallow earthquakes are expressed by well-pronounced active surface faulting. Comparison of seismicity of Armenia and the Caucasus with tectonic setting shows that all the strong earthquakes are associated with the active blocks, their edges, and junctions. The analysis of the focal mechanisms of earthquakes with various magnitudes shows the presence of all fault types in Armenia: strikeslip, normal, reverse, thrust, oblique, normal faulting with various components, and with prevailing strike-slip faulting. The combinations of exposure depend on the relatively neighboring block movements. The quality of the Armenian National Catalogue is discussed and the representativeness is described. A unified and homogeneous earthquake catalog is a base for analysis—determination of catalog completeness, recurrence and activity rates, etc., which are the key input parameters for probabilistic seismic hazard assessment.

Promotional text: A sub-network of 6 stations has been deployed in 2018 and 2019 on the Armenian territory thanks to a technical and scientific collaboration between the RSSP and the CEA/DASE aimed at improving the completeness magnitude of the catalog.

P2.3-647 – Microseismic Activity in Armenian Upland

Author: Sos Margaryan[1]
Co-authors: Yoann Cano[2]; Gevorgyan Ani[1]; Juharyan Aleksan[1]
[1]*Armenian National Survey for Seismic Protection (NSSP), Armenia*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: msos78@hotmail.com

Seismic networks are a source of valuable data for seismological research. Since 2010 in cooperation with the French CEA/DASE, the broadband seismic network in Armenia has been upgraded. Digital seismological stations were deployed in the territory of Armenia and they are providing data that enabled to conduct of various research activities, including the study of microseismicity and active tectonics in the region. The seismicity of the Armenian Upland relates to the collision of Arabian and Eurasian plates, which is characterized by a diffusive distribution of shallow earthquakes of various magnitudes. The strong shallow earthquakes as well as microearthquakes are expressed by well-pronounced active surface faulting. The microearthquake pattern observed over the past few years is consistent with the tectonic pattern of the study area including historical seismicity. In general, the seismicity in the Armenian Upland correlates with the known geologic structures. The microseismic activity also was studied from the point of view of large crustal earthquakes preceding.

Promotional text: A sub-network of 6 stations has been deployed in 2018 and 2019 on the Armenian territory thanks to a technical and scientific collaboration between the RSSP and the CEA/DASE aimed at improving the completeness magnitude, quality and representativeness of the catalog.

P2.3-671 – Use of Small-Aperture, Near-Source Seismoacoustic Arrays in Characterizing Low-Yield Chemical Explosive Sources

Author: Claire Perry[1]
Co-authors: David McCormack[1]; James Morawetz[1]; Nicholas Jason Ackerley[1]; Reid van Brabant[1]
[1]*Canadian National Data Centre, Natural Resources Canada*
Corresponding Author: claire.perry@canada.ca

Ground-truth (GT) recordings of low-yield quarry blasts at near-source distances provide a means of assessing the accuracy of seismoacoustic arrays in detecting and characterising explosive events. Infrasonic recordings from surface explosions generally show superior signal-to-noise (SNR) ratios compared to seismic detections, however dynamic atmospheric conditions introduce uncertainty. For detection of low-yield explosions in urban environments, small-aperture arrays of collocated seismic and acoustic sensors should perform well in a greater variety of conditions. We deployed two six-node, small-aperture seismoacoustic arrays in near Labrador City and Ottawa, Canada, over month-long periods. Using an empirical approach, we develop amplitude and period scaling relationships for estimating yield at distances 3-70 km using GT event details (timing, location, explosive yield) provided by mine and quarry operators. The sources are ripple-fire detonations spaced milliseconds apart. The blast durations are ~10-30 seconds, and origin times are generally accurate to within seconds. Blast yields are 3-1000 T of TNT equivalent and associated seismic magnitudes are approximately 1.3-2.9 MW. We show that seismoacoustic data are complementary and, when combined, result in more accurate blast characterisation.
Promotional text: This study focuses on improving our understanding of seismoacoustic characteristics of low-yield explosions at near-source distances, with applications to urban seismoacoustic monitoring arrays.

P2.3-708 – Remote Hydroacoustic and Infrasonic Detection and Characterization of Eruptive Activity Leading to, During and Following the December 2018 Major Flank Collapse and Tsunami at Anak Krakatau

Author: Kaelynn Rose[1]
Co-author: Robin Matoza[1]
[1]*University of California, Santa Barbara, CA, USA*
Corresponding Author: kaelynn@ucsb.edu

A climactic eruption phase on December 22, 2018 triggered the collapse of the southwest flank and summit of Anak Krakatau stratovolcano, generating a tsunami which struck Sumatra and Java. We employ a selection of remote moored hydroacoustic (H08S, 3,307 km; H01W, 3,720 km) and infrasonic (IS06, 1,156 km; IS07, 3,475 km; IS52, 3,638 km) stations of the International Monitoring System (IMS) to investigate eruptive activity preceding, during, and after the climactic eruption phase. We observe 6 months of co-eruptive intermittent infrasound at IS06, and powerful infrasound from the climactic eruption on IS06 and IS52. The climactic eruption phase was not detected hydroacoustically, but we observe a ~12-day swarm of hydroacoustic signals beginning 24 days before the flank collapse event that we attribute to sustained submarine eruptive activity at Anak Krakatau. We perform waveform multiplet analysis to assess similarity of infrasound and hydroacoustic events. Impulsive infrasonic events recorded during the main infrasound-generating eruption are similar, indicating repetitive explosions at Anak Krakatau. Hydroacoustic event families at H08S are less similar, indicating a possible range of submarine eruption processes and signal types. This study further underscores the potential of remote acoustic technology for detecting and characterizing eruptions at submarine or partially submerged volcanoes.
Promotional text: We conduct a multi-technology analysis using infrasonic and hydroacoustic stations of the International Monitoring System (IMS) to remotely detect volcanic signals leading up to, during, and after the 2018 major flank collapse eruption of Anak Krakatau.

T2.4 Atmospheric and Subsurface Radionuclide Background and Dispersion

Highlights

Added Value of Atmospheric Modelling in Understanding Radionuclide Background

O2.4-056 described the efforts undertaken in the framework of the 3rd ATM Challenge, an international exercise that aims to understand the radioxenon background. The ultimate goal of this exercise was to provide an ensemble analysis of radioxenon background levels at IMS stations located in the Northern Hemisphere, which are frequently impacted by industrial emissions. In reference to this presentation, P2.4-637 proposed options for organizing and setting up simulations for complex or computing-intensive tasks that could be useful for participants in the 3rd ATM Challenge, using the FLEXPART dispersion model.

O2.4-510 presented the analysis of the radioxenon detections observed by the new generation SPALAX-NG system near Paris in 2019. The high sensitivity of the system enabled a large amount of multi-isotopic detections, including ^{133}Xe, ^{135}Xe and ^{131m}Xe. The ATM results showed that observed detections came not only from the main emitter in Fleurus, Belgium, but also from the local producer of radioelements for medical purposes, which is located in Saclay, 15 km north-west of the SPALAX-NG test site.

P2.4-563 and P2.4-480 presented comparisons between measured and simulated radioxenon concentrations using ATM and real time stack emission data from the medical isotope production facility in Fleurus, Belgium. The first poster analysed detections at IMS stations in Sweden and Germany, and the second analysed radioxenon detections at an IMS-like system in the United Kingdom. One of the conclusions was that the simulation of ^{133}Xe in near real time using stack data might improve our understanding of the xenon background.

P2.4-037 applied the global atmosphere-chemistry model EMAC to simulate the dispersion and deposition of radionuclides, such as ^{137}Cs, ^{131}I and ^{133}Xe, released from the Fukushima Daiichi nuclear accident. To evaluate model performance, modelled surface concentrations were compared with IMS station observations that were made available through vDEC.

P2.4-335 discussed the effect of 2020 Chernobyl Exclusion Zone wildfires on the IMS radionuclide station network. ATM simulations were used to identify which IMS stations were influenced by plumes from Chernobyl. For the selected stations, the effect of the wildfires was assessed through analysis of the measured activity concentration of ^{137}Cs and, in parallel, analysis of the ^{137}Cs to ^{40}K ratio.

P2.4-590 evaluated the potential benefit of ensemble dispersion modelling for CTBT applications with input data from the Ensemble Prediction System of ECMWF. It was demonstrated for five different test cases that the possible source region (PSR), i.e. the correlation coefficients between the measured and simulated activity concentration values based on ATM, calculated for each grid point in space and time, can be reduced in size. It was concluded that the meteorological uncertainty to a large degree could be covered by the 10 member subset because forecast uncertainty was largely suppressed due to concatenating analyses and short term forecasts.

Xenon Isotopes Attributed to Activation Sources

O2.4-138 reported on observations of environmental ^{125}Xe, ^{127}Xe and ^{129m}Xe during the testing of Xenon International, a next-generation xenon measurement system. They are believed to be the first observations of these isotopes in environmental samples collected by automated radioxenon systems. The isotopes have been attributed to the High Flux Isotope Reactor (USA) located about 20 km away. These isotopes would interfere with the quantification of the radioxenon isotopes collected by the IMS. Implications for IMS systems were presented, and possible mitigation strategies were proposed.

P2.4-607 investigated whether radioxenon generated by activation sources such as the High Flux Isotope Reactor (USA) or strong spallation neutron sources could be observed by the IMS noble gas system. The case studies give evidence that the spallation neutron source at the Japan Proton Accelerator Research Complex (J-PARC) can explain observations of ^{133}Xe and ^{135}Xe at the IMS station in Takasaki that cannot be explained by any other known source. The conclusions of this study have important implications for assisting States in identifying the source of a specific event and for deciding on whether interference corrections for non-traditional radioxenon isotopes generated by activation need to be introduced to the operational software.

Statistical Approach to Atmospheric Background

O2.4-709 presented two statistical methods, parametric and non-parametric, that when applied to ^{133}Xe activity concentration measurements allowed for better understanding of the atmospheric background and anomalous values. The parametric method consists of two control charts: the Single Observation Control (SOC) chart, which is sensitive to large variations with respect to the mean value, and the Exponentially Weighted Moving Average (EWMA) chart, which is sensitive to small variations with respect to the mean value. The parametric method allows for better understanding of false positives. The non-parametric method, based on a Recursive Segmentation and Permutation (RS/P) algorithm, can help in understanding anomalous values. O2.4-406 shared the first results of the application of the parametric method to study ^{137}Cs detections at IMS station RN43 in Nouakchott, Mauritania. The aim was to reveal seasonality, possible sources of ^{137}Cs and correlation with atmospheric phenomena. Further examples of application of the parametric and non-parametric methods to radioxenon data were given in P2.4-260 and P2.4-261, respectively.

P2.4-125, based on a statistical analysis of variability in background radioxenon, revealed important factors associated with fluctuations in radioxenon at IMS stations. The radionuclide background fluctuates due to synoptic weather events, temporal changes in background sources, and site specific details related to the placement of IMS stations. The data set, including historical IMS measurements, weather reanalysis products, high resolution spatial topographic and land use data, and a large collection of ATM simulations, were used to assess the relationship between potential background sources, site specific characteristics and signals at IMS stations.

P2.4-307 discussed spatial and temporal variations of the anthropogenic radionuclides ^{137}Cs and ^{134}Cs in ground-level air samples collected between 2011 and 2020 by IMS stations located on the African continent.

P2.4-421 discussed the evolution of the background for four radioxenon isotopes (^{131m}Xe, ^{133}Xe, ^{133m}Xe and ^{135}Xe) between 2015 and 2020.

P2.4-551 studied the radioxenon background at IMS station RN63 in Stockholm, Sweden, between 2012 and 2019. Work focused on understanding potential sources and their contributions to detections at the station. Detections were characterized with respect to concentrations, isotopes detected and wind direction.

P2.4-606 summarized the best estimates of radioxenon emissions from all nuclear facilities in the year 2014. For nuclear power plants in Europe and the USA, the reported releases for the whole year were applied in combination with information about their operational schedule. Best estimates were used for all other nuclear power plants and for the strongest research reactor sources. This unique data set was one of the important inputs used by participants in the 3rd ATM Challenge.

Towards the Reduction of Radionuclide Emissions

O2.4-106 provided a review of the production processes of ^{99}Mo without use of any uranium material. The first path is via neutron capture utilizing a research reactor. In this pathway, NorthStar (USA) can use either high-purity natural molybdenum discs or target material of enriched ^{98}Mo. The second path is the use of electron accelerators to perform photon transmutation using enriched ^{100}Mo target material. In either case, emissions of gaseous radioisotopes of krypton, iodine or xenon by NorthStar are virtually non-existent.

P2.4-405 discussed different alternatives for reducing noble gas emissions to the environment due to the production of radioisotopes by fission.

P2.4-080 reported on efforts to minimize the impact of radioxenon emissions. For that purpose, atmospheric transport models were applied at INVAP (Argentina) during different stages of the design and development of nuclear facilities. Examples of different capabilities and results for different cases were shown.

Monitoring of Xenon Emission Data from Civil Sources

P2.4-206 introduced the Xenon Environmental Nuclide Analysis at Hartlepool (XENAH) project, a collaboration between scientists from the United States and the United Kingdom with the aim to better characterize the radionuclide emissions of a nuclear power reactor. Measurements took place at the Hartlepool Nuclear Reactor in England with cooperation of the reactor operator. To collect data, three monitoring techniques were used: stack monitoring of radioxenon emissions at the source, stand-off measurements of radioxenon after atmospheric transport of several kilometres, and ultra-low background measurements of relevant environmental samples collected at and near the reactor.

P2.4-211 gave a brief overview of the Source Term Analysis of Xenon (STAX) project, with a focus on data processing and analysis infrastructure. STAX is an experimental network of sensors to detect and quantify emissions of xenon isotopes from medical isotope production facilities and other nuclear facilities. These data can be accessed using the interface that is available to authorized users.

P2.4-078 reported on the status of the INVAP STAX monitor, including a general description, calibration and configuration of both software and hardware. The work was done in the framework of the STAX project (see P2.4-211).

Source Term Reconstruction

P2.4-360 discussed a contribution to the NPE in 2019, and described work on radionuclide data analysis, ATM in backward mode by FLEXPART and source reconstruction in a Bayesian method.

P2.4-373 presented an algorithm that can determine the release location and other source parameters by making use of radionuclide observations (both detections and non-detections) and source–receptor sensitivities provided routinely by CTBTO. The Bayesian approach inherently takes into account uncertainties.

P2.4-427 compared the results generated by two source estimation algorithms: WEB-GRAPE, developed by CTBTO, and

EgNDC-SRC, recently developed by the NDC of Egypt. For that purpose, ATM of synthetic experiments and some real events that had detections at IMS stations were used.

P2.4-523 performed a modelling study to test whether dry and wet deposition measurements can complement existing airborne measurements for source reconstruction purposes. In this context, drawbacks and advantages were discussed.

Measurement Campaigns

P2.4-552 presented the preliminary analysis results of an ongoing temporary radioxenon background measurement campaign in Japan. Two transportable noble gas systems, deployed in Horonobe and Mutsu in 2018, together with IMS station RN38 in Takasaki, form a temporary high-density configuration network enabling observation of the same event release at different locations at distances of about 500 km from each other.

P2.4-553 reported the results related to subsoil measurements of radioxenon and radioargon in the region of Kvarntorp, Sweden. The measurements were carried out over a period of two weeks. The analytical results from the collected samples were discussed in relation to radon levels, soil uranium content and meteorological conditions.

P2.4-308 discussed the ultra-sensitive gamma spectrometry measurements of environmental samples from the Hartlepool Nuclear Reactor in the United Kingdom.

Towards Detecting an Underground Nuclear Explosion

O2.4-477 presented the results of a series of highly instrumented mesoscale experiments that provided an opportunity to better understand the interaction between source strength and location, natural variations in rock competency, explosion-induced rock damage, and gas migration. Rock damage was imaged in 3-D using a novel combination of water injection, draining, heating and drying combined with time-lapse electrical resistivity tomography. Results showed that the influence of geologically weak zones on rock damage and gas flow were comparable to the influence of source strength and location. Results provided insight that should be considered in detecting nuclear explosions through atmospheric gas sensing.

P2.4-217 performed microscale studies of the formation of particulate and the transport of gaseous species within a variety of geologic media. Understanding the transport of gaseous and particulate signatures that are produced during an underground nuclear explosion allows for a better understanding of the signals available for detection within the IMS.

P2.4-258 presented a code that was developed for two phase flow, tracer transport and thermal effects through a fractured porous medium under the action of constant or time dependent pressure fluctuations. The fractures were modelled as surfaces with specific properties; the fluid properties were assumed to be dependent on pressure and temperature.

Decisions on Nuclear Emergency Response

P2.4-088 addressed the use of computational fluid dynamics as a complimentary tool to support decisions related to nuclear emergencies, involving the atmospheric dispersion of radionuclides, and to analyse a possible underground nuclear explosion.

P2.4-274 presented the results of a theoretical study to determine the shielding against ionizing radiation from atmospheric dispersion arising from a radiological accident in a small nuclear reactor.

P2.4-461 reported on the strategy for protection against chemical, biological, radiological and nuclear threats developed for the Austrian Armed Forces in the framework of the project ABC-MAUS. The approach includes a few steps. As soon as an explosion is identified based on infrasound and seismic measurements, forward ATM with a predefined release term is undertaken to understand which area might be contaminated. In the final step, when the radiological measurements become available, the source term is adjusted.

Other Topics

P2.4-090 presented the comparative study of the transient and steady state thermal hydraulics analysis of the low enriched uranium core of Ghana Research Reactor-1 (GHARR-1).

P2.4-099 reported on the development of new ways to measure concentration activities of ^{131}I using direct and indirect methods in radioisotope production stacks, in the environment and in settlements (indoor and outdoor).

P2.4-169 gave an overview of efforts related to the search for small temporal modulations of half-lives of radionuclides in the IMS quality control data.

O2.4 Atmospheric and Subsurface Radionuclide Background and Dispersion Abstracts of Oral Presentations

O2.4-056 – Results of the 3rd ATM Challenge 2019

Authors: Christian Maurer[1]; Jolanta Kusmierczyk-Michulec[2]; Jonathan Bare[2]; Alain Malo[3]; Alice Crawford[4]; Pierre Bourgouin[2]; Martin B. Kalinowski[2]
[1]*Central Institution for Meteorology and Geodynamics (ZAMG), Vienna, Austria*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
[3]*Canadian Meteorological Centre, Gatineau, Quebec, Canada*
[4]*National Oceanic and Atmospheric Administration - Air Resources Laboratory, Maryland, USA*
Corresponding Author: christian.maurer@zamg.ac.at

Estimating the radioxenon background based on a multi-input-multi-model ensemble modelling approach at IMS stations having frequent detections was the main goal of the 3rd ATM-Challenge. The Challenge included four selected IMS stations. Participants were invited to calculate contributions to the signal captured in daily samples at CAX17 (St. John's), DEX33 (Schauinsland/Freiburg), SEX63 (Stockholm) and USX75 (Charlottesville) for up to 6 months. Up to 30 submissions per station from 16 different institutions were finally received. Xe-133 stack emission data with daily temporal resolution for the time period June to November 2014 provided by IRE (Belgium) and CNL (Canada) radiopharmaceutical plants were used. In addition, publicly available emission estimates for nuclear power plants and research reactors as well as annual emissions from several other well-known facilities were also made available to participants. The presentation will summarize the comprehensive results from this study. First, the added value of training an optimized ensemble per station will be discussed. Second, the beneficial impact of including contributions from minor emitters and thus rough emission estimates thereof will be demonstrated. The added value of

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

simulating samples highly influenced by main emitters, i.e. radiopharmaceutical plants, based on actual daily emission data will be exemplified.

O2.4-106 – Production of Mo-99 Without Use of Uranium

Author: James Harvey[1]
[1]*NorthStar Medical Technologies, LLC, Beloit, USA*
Corresponding Author: jharvey@northstarnm.com

NorthStar has embarked on two parallel paths to produce Mo-99 and other medical radioisotopes without use of any uranium material. The first path, which was approved by the US FDA in February 2018, is via neutron capture utilizing a research reactor. In this pathway, NorthStar can use either high-purity natural molybdenum discs or can use target material of enriched molybdenum-98. This pathway has successfully been producing Mo-99 and delivering to the US market for more than two years. The second path, scheduled for production start in late 2022, is the use of electron accelerators to perform photon transmutation using enriched molybdenum-100 target material. In either case, NorthStar's emissions of gaseous radioisotopes of krypton, iodine or xenon are virtually non-existent. This presentation will provide a review of the production processes and an update to current program status.

O2.4-138 – First Observations of Environmental ^{125}Xe, ^{127}Xe and ^{129m}Xe

Author: James Ely[1]
Co-authors: Matthew Cooper[1]; James Hayes[1]; Michael Mayer[1]; Justin McIntyre[1]; Mark Panisko[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: james.ely@pnnl.gov

Environmental ^{125}Xe, ^{127}Xe, and ^{129m}Xe have been observed during testing of a next-generation xenon measurement system, Xenon International. The observations of these three radioxenon isotopes occurred during routine testing at the Xenon International manufacturing facility in Knoxville, Tennessee, USA, and they are believed to be the first observation of these isotopes in environmental samples collected by automated radioxenon systems. The observations are consistent with activation of xenon in air and have been attributed to the High Flux Isotope Reactor (HFIR) located at the Oak Ridge National Laboratory, about 20 km away. The ^{125}Xe, ^{127}Xe, and ^{129m}Xe isotopes can be detected in the beta-gamma detector of Xenon International and would interfere with the quantification of the radioxenon isotopes used for nuclear explosion monitoring. The interferences would cause elevated concentration values for the radioxenons of interest in the current analysis methodology. The ^{125}Xe was observed the most often, and it decays to ^{125}I, which can also interfere with radioxenon measurements in the beta-gamma detector. This presentation will describe the observations, production mechanisms, implications for IMS systems and possible mitigation strategies.

Promotional text: This presentation provides understanding of radioxenon background and potential interferences to the International Monitoring System radioxenon systems.

O2.4-406 – Statistical Study of the Cs-137 Detections at RN43 Station

Author: Mohamed Mahmoud Mounja[1]
Co-authors: Antonietta Rizzo[2]; Giuseppe Ottaviano[2]; Claudia Sanguigni[2]
[1]*Mauritania National Authority of Radiation, Safety and Nuclear Security (ARSN), Nouakchott, Mauritania*
[2]*Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Italy*
Corresponding Author: elhadi320@hotmail.com

This work is the result of a joint collaboration between the Italian and the Mauritanian National Data Centers. Radionuclide station RN43 in Mauritania was established in Nouakchott on

6 November 2006. The historical analysis of the occurrence of relevant radionuclides at RN43 over the past ten years showed that the main contributor was Cs-137, causing several level 3 and level 4. A descriptive statistical analysis of the Cs-137 occurrence was performed and two types of parametric process control methods were applied: the "Shewhart Control Chart" and the "Exponentially Weighted Moving Average (EWMA) Control Chart". The results of both methods were then analyzed in order to reveal seasonality, possible sources of Cs-137 and correlation with atmospheric phenomena.
Promotional text: Desert wind is blowing cesium from the desert to the ocean.

O2.4-477 – 3-D Electrical Imaging of Mesoscale Rock Damage Patterns from Underground Chemical Explosions

Authors: Tim Johnson[1]; Hunter Knox[1]; Chris Strickland[1]; Justin Lowrey[1]; Christine Johnson[1]; Eric Robey[2]; Mathew Ingraham[2]; Kirsten Chojnicki[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
[2]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
Corresponding Author: tj@pnnl.gov

Atmospheric gas detection is a primary means for detecting and verifying underground nuclear explosions. Subsurface gas migration is governed by a complex system of unknown variables, including the interaction between geology, explosion-induced stresses and corresponding rock damage patterns that provide primary gas flow pathways. The U.S. is conducting a series of highly instrumented mesoscale experiments that provide an opportunity to better understand the interaction between source strength and location, natural variations in rock competency, explosion-induced rock damage, and gas migration. Rock damage is imaged in 3-D using a novel combination of water injection, draining, heating and drying combined with time-lapse electrical resistivity tomography. Corresponding measurements of induced gas breakthrough times at discrete points in exterior monitoring wells are being used to understand how rock damage is influenced by local geology, and how it influences gas migration away from the source point. Results show that the influence of geologically weak zones on rock damage and gas flow are comparable to the influence of source strength and location. This result has important implications for larger scale underground explosions, and how those explosions interact with geology and alter gas migration flow paths and travel times to the surface.
Promotional text: This work discusses subsurface properties and how they interact with underground explosions to govern gas-phase breakthrough times and locations at the surface. Results provide insights that should be considered in detecting nuclear explosions through atmospheric gas sensing.

O2.4-510 – Six Months of Radioxenon Detections by the SPALAX New Generation System Near Paris in 2019

Authors: Pascal Achim[1]; Sylvain Topin[1]; Philippe Gross[1]; Sylvia Generoso[1]; Antoine Cagniant[1]; Olivier Delaune[1]; Mireille Morin[1]; Thomas Philippe[1]; Jean-Pierre Fontaine[1]; Christophe Moulin[1]; Guilhem Douysset[1]; Gilbert Le Petit[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: pascal.achim@cea.fr

As part of its qualification process by the PTS, the SPALAX-NG - noble gas - New Generation system was operated from October 2018 to April 2019 on the CEA/DAM premises near Paris (France). The new generation system's high performances contribute significantly to increase the number of detections and to improve the knowledge of the radioxenon background. Indeed, in this study, a major dataset including numerous isotopic ratios is established for Western Europe that enables to refine the characterization of the background sources and the discrimination criteria. In addition, a full Atmospheric Transport Modelling study has been performed from this full dataset, that allows to (1) reconsider the radioxenon source terms of the main emitter in Western Europe (IRE, Fleurus, Belgium), and to (2) detect for the first time some very local and non-traditional sources that can influence the categorization of a detection.

Promotional text: Major improvement in radioxenon detection capacity and background knowledge in Europe.

O2.4-709 – Statistical Study of the IMS ^{133}Xe Data Distributions, Using Both a Parametric and a Non-Parametric Method

Authors: Giuseppe Ottaviano[1]; Michele Scagliarini[2]; Antonietta Rizzo[1]; Rosanna Gualdi[2]; Sofia Guernelli[2]; Claudia Sanguigni[2]; Luca Ferri[2]; Franca Padoani[1]

[1]*Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Italy*

[2]*University of Bologna, Bologna, Italy*

Corresponding Author: giuseppe.ottaviano@enea.it

The aim of this work is to apply both a parametric and a non-parametric statistical method to the ^{133}Xe activity concentrations measured at noble-gas stations of the IMS of the CTBTO, in order to investigate the atmospheric background and the anomalous values. The parametric method consists of two control charts: a single-observation chart sensitive to large variations with respect to the mean value, and an EWMA chart sensitive to small variations with respect to the mean value. The results show that the control charts could be useful for an NDC carrying out daily monitoring to easily detect significant variations of the activity concentrations, and to perform more specific analysis of the anomalous values. The parametric method is expected to be useful to better understand the false positives. The non-parametric method is based on a Recursive Segmentation and Permutation (RS/P) algorithm, it does not require any assumption about the underlying probability distribution, and it associates a significance level to the results. The RS/P method is useful for detecting single or multiple mean shifts and/or scale shifts, and the results show that it can be useful to highlight any random oscillations of the phenomenon providing a likely better understanding of anomalous values.

Promotional text: The main contribution of the present abstract is about a better understanding of the Xe-133 background and anomalous values applying two advanced statistical methods to the activity concentration values measured at the noble gas stations of the IMS.

P2.4 Atmospheric and Subsurface Radionuclide Background and Dispersion Abstracts of Poster Presentations

P2.4-037 – Comparison of Modelled Atmospheric Radionuclides from the Fukushima Daiichi Nuclear Accident with CTBTO Station Measurements

Author: Theodoros Christoudias[1]

[1]*The Cyprus Institute, Nicosia, Cyprus*

Corresponding Author: christoudias@cyi.ac.cy

The global atmospheric dispersion and deposition of radionuclides released from the Fukushima Dai-ichi nuclear power plant accident was modelled using the EMAC atmospheric chemistry – general circulation model at different resolution (equivalent to ~50 km and ~110 km Gaussian grid). The model accounts for emissions and transport of the radioactive isotopes ^{131}I and ^{137}Cs, and removal processes through precipitation, particle sedimentation and dry deposition. In addition, we simulated the release of ^{133}Xe, a noble gas that can be regarded as a passive transport tracer of contaminated air. Modeled surface concentrations were compared to station observations by the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO) global monitoring network for a number of stations through the CTBTO Virtual Data Exploitation Centre.

Promotional text: We present a scientific application of the data used for test ban verification, by comparing modeled surface concentrations to station observations by the CTBTO global monitoring network after the Fukushima NPP accident, to evaluate model performance and investigate impacts.

P2.4-078 – First Results with INVAP STAX Monitor

Authors: Federico Fernandez Baldis[1]; Mauro Nunez[1]; Roman Pino[1]; Andres Zapata[1]; Mariana Di Tada[2]; Eduardo Nassif[1]; Ricardo Sagarzazu[1]; Horacio Boccoli[1]; Eduardo Carlos Carranza[3]
[1]*INVAP S.E., Bariloche, Argentina*
[2]*CONICET, Instituto Tecnológico de Buenos Aires (ITBA), Buenos Aires, Argentina*
[3]*National Atomic Energy Commission (Comisión Nacional de Energía Atómica), Argentina*
Corresponding Author: ffbaldis@invap.com.ar

A general description of INVAP STAX monitor final status is shown, including calibration and software/hardware configuration. First measurements results obtained in a real Noble Gas emission environment (MIPF plant at Ezeiza Atomic Center, CNEA, Buenos Aires, Argentina) are presented. Equipment measurement ranges, mainly focused to low flow rate and high activity concentration emissions, are discussed.
Promotional text: Radioxenon accurately detection of high concentration emissions at MIPF such as EZEIZA (CAE, CNEA, ARGENTINA) is improved with the new STAX monitor manufactured by INVAP.

P2.4-080 – Atmospheric Transport Model Applied to the Design of Nuclear Facilities

Author: Mariana Alessi[1]
[1]*INVAP S.E., Bariloche, Argentina*
Corresponding Author: malessi@invap.com.ar

Xenon emissions from medical isotope production facilities (MIPFs) and other nuclear installations affect the verification capability of the International Monitoring System (IMS) of the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO). In an effort to minimize the impact of this radioxenon and in order to mitigate, in general, the radionuclide emission, Atmospheric Transport Models are applied at INVAP on different stages of the design and development of type of facilities. The design includes safety protection radiological analyses, either inside or outside the installations, and monitoring of gaseous effluent release into the atmosphere considering both normal operation as well as accidental cases. In this work, examples of different capabilities and results for different cases are shown. The safety analyses are based on conservative Gaussian Plume models, which include the evaluation of systems performance, operational cases, atmospheric dispersion and transport of radionuclides, meteorological conditions, emission parameters and site characteristics.
Promotional text: This work done by INVAP contributes to the global effort and commitment promoted by the CTBTO to minimize the impact of radioxenon and in general of radionuclides emissions through the development and application of ATM on different stages of the design in nuclear facilities.

P2.4-088 – Applications in CFD in Nuclear Emergency Response Decisions

Author: Carlos Eduardo Santos Bonfim[1]
Co-authors: Tercio Brum[1]; Jorge Alberto Valle Da Silva[1]; Felipe Barbosa Ougano[1]; Rodrigo Carneiro Curzio[1]
[1]*CBRN Defence Institute (Brazilian Army), Rio de Janeiro, Brazil*
Corresponding Author: bonfim.carlos@eb.mil.br

The atmospheric dispersion modeling of radionuclides is used to obtain responses to emergencies by estimating radiation effects, associated with the atmospheric release of radioactive materials. Nowadays, almost all software used for these purposes, is based on the Gaussian model, which provides fast and conservative means that consider regions free of obstructions and simple weather conditions. However, when it comes to calculate radiological impacts from radionuclide transport to recover the affected area in complex regions close to the event, considering the physical or physico-chemical phenomena of the flow, the radioactive-cloud spreading time, the concentration and effective dose levels, and both time and environmental impact on the reached area, we need to use more robust tools to assist us in decision making. Hence, this work aims to address the use of computational fluid dynamics as a differentiated and complementary tool to support decisions related to nuclear emergencies, involving the atmospheric dispersion of radionuclides, and to analyze a possible underground nuclear explosion, based on the calculation of radioxenon surface flow regarding yields, detonation depths and distinct permeabilities.

Promotional text: The objective of the work is to show the application of CFD, as a differentiated and complementary tool for data analysis and characterization of relevant events to the Treaty. Being able to contribute in the exchange of knowledge between CTBTO and the scientific community.

P2.4-090 – Comparative Study of the Transient and Steady State Thermal Hydraulics Analysis of the Low Enriched Uranium Core of Ghana Research Reactor-1 (GHARR-1)

Author: Prince Amoah[1]
Co-authors: Edward Shitsi[2]; Emmanuel Ampomah-Amoako[1]
[1]*Nuclear Regulatory Authority, Accra, Ghana*
[2]*Ghana Atomic Energy Commission (GAEC), Accra, Ghana*
Corresponding Author: p.amoah@gnra.org.gh

Countries seeking a quick bomb or would-be nuclear terrorists have eyes on poorly secured sites that contain significant quantities of high enriched uranium, (HEU). HEU is the material of choice for states or terrorists that seek to proliferate stealthily without testing their weapons. It is therefore critical to make current stocks of HEU as inaccessible as possible. One of the most effective long term approach is to eliminate it from as many locations as possible and convert the HEU cores to low-enriched uranium (LEU) core. The high enriched uranium core of the Ghana Research Reactor-1 has been converted to a low enriched uranium core. The transient and steady state thermal hydraulic analysis of the LEU core of Ghana Research Reactor-1 is presented in this work. The Monte Carlo N Particle code (MCNP-5) was used in obtaining neutronic parameters for the transient and steady state simulations. PARET/ANL was used in simulating transient responses of the GHARR-1 LEU core and PLTEMP/ANL was also used for the steady state simulations. Results obtained in both transient and steady state compared well with the experimental data.

Promotional text: The global concern on Nuclear Non-Proliferation has been heralded by a core conversion of HEU cores of Research Reactors to LEU cores, this paper focuses on thermal hydraulic evaluation of Ghana's LEU core after the core conversion.

P2.4-099 – Development of New Methods for Measuring Concentration Activities I-131 Using Direct and Indirect Methods in Radioisotope Production Stacks, in the Environment and in Settlements (Indoor and Outdoor)

Author: Gatot Suhariyono[1]
Co-author: Susilo Widodo[1]
[1]*Indonesia National Nuclear Energy Agency (BATAN), Jakarta, Indonesia*
Corresponding Author: g_suhariyono@batan.go.id

Radioisotope Production Facility in Serpong, has produced and processed I-131 which can be dispersed to residential areas and the environment around the Serpong Nuclear Zone (SNZ). Measurement of the air release dispersion I-131 using an old analogue tool is not functioning, and only a charcoal filter is functioning in the stack of the isotope production facility. Measurement of the I-131 dispersion to the environment and houses around SNZ has not been carried out. Therefore, it is necessary to develop a new method of measuring the release of I-131 concentration in the stack combined with equipment from the CTBTO and I-131 measurement in the environment and settlements (indoor and outdoor) around the SNZ. Direct measurements using a portable in-situ NaI(Tl) detector were carried out in the house, environment, and using the LaBr3 detector in the stack. Indirect measurements using charcoal filters and vacuum pumps were carried out in the stack and outdoors. The newly developed I-131 discharge measurement method can be used to replace the I-131 analog method, because the new measuring system can be operated rapidly and continuously. The concentration of I-131 during rain and high humidity tends to increase, while the presence of sunlight reduces the concentration of I-131.

P2.4-125 – Characterizing the Background Variability of Radionuclides at International Monitoring System Stations

Author: Donald Lucas[1]
Co-authors: Lee Glascoe[1]; Giselle Fernandez[1]
[1]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: ddlucas@llnl.gov

A variety of factors influence the atmospheric background of ubiquitous radionuclide signatures, like xenon-133, measured at International Monitoring System (IMS) stations. Variability in the radionuclide background obscures the categorization and discrimination of signals from nuclear weapons testing and civilian and industrial activities tied to medical radioisotope production and nuclear power reactors. The radionuclide background fluctuates due to synoptic weather events, temporal changes in background sources, and site-specific details related to the placement of IMS stations. To better characterize the radionuclide background, we have statistically analyzed a set of factors that may be associated with background variability. These factors include historical IMS measurements, weather reanalysis products, high-resolution spatial topographic and land-use data, and a large collection of atmospheric transport modeling simulations. We use this dataset to assess the relationships between potential background sources, site-specific characteristics, and signals at IMS stations, including an assessment of stations susceptible to large variations in background. This assessment may improve our understanding of the radionuclide background and may aid event characterization and analysis of data at the International Data Centre.

Promotional text: A statistical analysis of variability in background radioxenon reveals important factors associated with fluctuations in radioxenon at IMS stations. This analysis is useful for characterizing and understanding the radionuclide background.

P2.4-169 – Search for Small Temporal Modulations of Half-Lives of Radionuclides in IMS Quality Control Data

Authors: John Gruenwald[1]; Gabor David[2]; Daniel Javorsek[3]; Shaun Little[4]
[1]*SNARE Inc., USA*
[2]*Brookhaven National Laboratory (SNARE), Upton, NY, USA*
[3]*Defense Advanced Research Projects Agency (DARPA), VA, USA*
[4]*General Dynamics Mission Systems (GDMS), Chantilly, VA, USA*
Corresponding Authors: tom.gruenwald@snareinc.com, david@bnl.gov

Half-lives of radioisotopes are thought of as absolute constants of Nature. However, since the 1980s several experiments indicated that small percent or sub-percent level temporal modulations may exist, potentially correlated to variations of the solar neutrino flux. The issue has been debated by the nuclear theory community, since it would imply some new mechanism influencing weak decays, and of fundamental importance for nuclear physics. One problem is that high quality data collected over extensive period of time are scarce. As regular part of their operation, the IMS monitoring stations take so-called quality control data daily, measuring a source of known isotopes for 30 minutes. The stations are at diverse geographic locations and using standardized equipment and sources. Such data are ideal to investigate long term, small

modulations of the half-lives due to an external influence, like solar neutrinos. We obtained and analyzed 15 years' worth of quality control data from 11 IMS stations for annual and higher frequency modulations. We will present the results of this analysis, including an upper limit of the amplitude of the modulations and suggestions for the design of a future high-sensitivity experiment, dedicated to settle the issue of temporal modulations of half-lives due to solar influence.
Promotional text: Eighteen years of International Monitoring System was analyzed for evidence of time variance of nuclear decay contents. Additional, special experiments on the equipment were analyzed to assess the effects of periodic sample movement.

P2.4-206 – XENAH: Xenon Environmental Nuclide Analysis at Hartlepool

Authors: Brian Milbrath[1]; Ashley Davies[2]; Matthew Goodwin[2]; Mark Arnold[3]; Craig Dohring[3]; Andrew Petts[3]; Michael Warren[3]; Theodore Bowyer[1]; Jonathan Burnett[1]; Judah Friese[1]; James Hayes[1]; Lori Metz[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
[2]*AWE Aldermaston, Reading, United Kingdom*
[3]*EDF Energy, Hartlepool, United Kingdom*
Corresponding Author: brian.milbrath@pnnl.gov

Scientists from the U.K. and the U.S. are collaborating to perform measurements involving three different radionuclide monitoring techniques with the collective goal of better characterizing radionuclide emissions of a nuclear power reactor and how those might affect the International Monitoring System. The Xenon Environmental Nuclide Analysis at Hartlepool (XENAH) collaboration will perform these measurements at the Hartlepool Power Reactor in northeast England with cooperation of the reactor operator, EDF Energy. The three radionuclide monitoring techniques are: stack monitoring of radioxenon emissions at the source, stand-off measurements of radioxenon after atmospheric transport of several kilometers utilizing sensitive air sampler/analyzers, and ultralow background measurements of relevant environmental samples collected at and near the reactor. Measurements began this year and will take place over 1 – 2 years. The measurement effort and techniques will be described, along with the scientific questions we plan to address.
Promotional text: Utilizing a stack monitor, stand-off detection via sensitive radioxenon sampler/analyzers, and ultralow background sample measurements at a nuclear reactor, U.K. and U.S. scientists are increasing understanding of radioxenon sources that may affect the IMS.

P2.4-211 – STAX Project: Data Analysis and Interactive Data Access

Author: Matthias Auer[1]
Co-authors: Sidney Hellman[1]; Mihaela Rizescu[1]
[1]*Instrumental Software Technologies Inc. (ISTI), Saratoga Springs, NY, USA*
Corresponding Author: matthiasauer@isti.com

The STAX (Source Term Analysis of Xenon) project aims at the development of a worldwide network to measure radioxenon isotopes released from medical isotope production facilities. A software package has been developed to fully process STAX data from secure data acquisition at the back end, to interactively viewing data at the front end. This presentation focusses on the analysis of data and on the viewing options of the software. An overall dashboard displays the STAX network state of operation and issues at specific stations can be diagnosed through a State-of-Health data viewing interface. In order to increase the confidence in analysis results, stack release data are analyzed in two parallel pipelines: at the STAX systems data are automatically analyzed using analysis software from the monitoring system manufacturers and on the central STAX server, data are analyzed using the autosaint software. Time series of both data sets can be viewed either individually or together and significant discrepancies between the two analysis pipelines can be displayed. User configurable time windows can be set to calculate emission values for specific time intervals. For each individual sample, the raw data as well as a spectrum chart can be accessed via the time series chart.

Promotional text: This works aims at improving the understanding of the contribution of Xenon background sources to the measured concentrations at IMS stations.

P2.4-217 – Isotopic Transport Variation as a Function of Environmental Conditions

Authors: Michael Foxe[1]; Elizabeth Denis[1]; Mindy Zimmer[1]; Heather Cunningham[1]; Kellen Springer[1]; Derek Haas[2]; Joseph Lapka[2]; Lance Hubbard[1]; Martin Liezers[1]; April Carman[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
[2]*University of Texas, Austin, USA*
Corresponding Author: michael.foxe@pnnl.gov

As gaseous and particulate signatures are produced during an underground nuclear explosion, it is important to understand their transport to the surface for subsequent atmospheric transport and detection. By understanding the transport throughout the subsurface, the atmospheric measurements have the potential to allow for a better understanding of the fractionation and total release fraction of radionuclides from a nuclear explosion. We have performed microscale studies of formation of particulate and transport of gaseous species within a variety of geologic media. In this presentation, we discuss the use of exploding wires to simulate the formulation of particulate and the use of inverse gas chromatography to characterize gas transport parameters for a variety of geologic media.

Promotional text: Understanding material transport in the subsurface through microscale laboratory experiments allows for a better understanding of the signals available for detection within the IMS.

P2.4-258 – Atmospheric and Subsurface Radionuclide Background and Dispersion

Authors: Aliaksei Pazdniakou[1]; Valeri Mourzenko[2]; Jean-François Thovert[2]; Eric Pili[3]; Pierre Adler[4]
[1]*Sorbonne Université, Paris, France*
[2]*Ecole Nationale Supérieure de Mécanique et d'Aérotechnique, Poitiers, France*
[3]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[4]*Université Pierre-et-Marie-Curie, Paris, France*
Corresponding Author: pierre.adler@upmc.fr

A general code has been developed to describe two phase flow, tracer transport and thermal effects through a fractured porous medium on the Darcy scale under the action of constant or time dependent pressure fluctuations. The fractures are modeled as surfaces with specific properties. The fluid properties can depend on pressure and temperature. The equations for flow, tracer concentration and temperature are discretized by the finite volume method on triangular and tetrahedral meshes. The three modules which compose the code, namely flow/energy/tracer transport are parallelized by the OpenMP technique and shown to function satisfactorily separately and in interaction. Applications of this code are made to a typical situation of interest with an underground cavity and a potential chimney. The dimensions of the geological medium above are 100x100x400m; it contains 147 fractures of radius 20 m and of equivalent aperture 1 mm. The fracture network is percolating from the cavity up to the surface. The initial pressure is 200 bars and the temperature 1000 K. All these characteristics can be modified at will. Pressure, temperature, and concentration evolutions as well as surface fluxes will be presented and discussed.

Promotional text: A code is developed for two phase flow, tracer transport and thermal effects through a fractured porous medium under the action of pressure fluctuations. The fractures are modeled as surfaces with specific properties. The fluid properties can depend on pressure and temperature.

P2.4-260 – Parametric Study of the Radioxenon Data Distribution, Measured at the Noble Gas Stations of the International Monitoring System of the CTBTO

Authors: Giuseppe Ottaviano[1]; Michele Scagliarini[2]; Antonietta Rizzo[1]; Sofia Guernelli[2]; Luca Ferri[2]; Claudia Sanguigni[2]; Franca Padoani[1]; Angelica Ciocca[2]
[1]*Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Italy*
[2]*Department of Statistical Sciences, University of Bologna, Italy*
Corresponding Authors: angelica.ciocca@studio.unibo.it, giuseppe.ottaviano@enea.it

The aim of this work is to apply a parametric statistical methodology to the radioxenon activity concentrations measured at noble gas stations of the International Monitoring System of the CTBTO, in order to investigate the radioxenon atmospheric background and the radioxenon anomalous values. The proposed parametric statistical methodology is based on the "Statistical Process Control" method and it consists of using two "Control Charts". The "Single Observation Control" Chart, sensitive to large variation of the measured values, could be useful for periodic monitoring of the phenomenon at the noble gas stations; the "Exponentially Weighted Moving Average" Chart, sensitive to small variations of the measured values, could be used to perform specific studies on the atmospheric background and on the anomalies of radioxenon activity concentrations.
Promotional text: Radioxenon is useful to potentially reveal underground nuclear explosions (UNEs) but it is also emitted by civil sources. To discriminate signals, advanced statistical methods are used to understand the background and the anomalous values that could be reasonably related to UNEs.

P2.4-261 – Non-Parametric Study of the Radioxenon Data Distribution, Measured at the Noble Gas Stations of the International Monitoring System of the CTBTO

Authors: Giuseppe Ottaviano[1]; Michele Scagliarini[2]; Antonietta Rizzo[1]; Rosanna Gualdi[2]; Franca Padoani[1]
[1]*Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Italy*
[2]*Department of Statistical Sciences, University of Bologna, Italy*
Corresponding Author: giuseppe.ottaviano@enea.it

The aim of this work is to apply a non-parametric statistical methodology to the radioxenon activity concentrations measured at noble gas stations of the International Monitoring System of the CTBTO, in order to investigate the radioxenon atmospheric background and the radioxenon anomalous values. The proposed non-parametric statistical methodology does not require any assumption on the underlying probability distribution of the raw data. The suggested method, based on Recursive Segmentation and Permutation (RS/P), allows to detect single or multiple mean and/or scale shifts.
Promotional text: Radioxenon is useful to potentially reveal underground nuclear explosions (UNEs) but it is also emitted by civil sources. To discriminate signals, advanced statistical methods are used to understand the background and the anomalous values that could be reasonably related to UNEs.

P2.4-274 – Shielding of Radiation from Atmospheric Dispersion Resulting from a Radiological Accident

Authors: Rodrigo Carneiro Curzio[1]; Carlos Eduardo Bonfim[2]; Rudnei Karam Morales[1]; Sergio Gavazza[1]; Domingos D'Oliveira Cardoso[1]
[1]*Military Engineering Institute, Brazil*
[2]*Army Technological Center, Brazil*
Corresponding Author: rodrigo.curzio@ime.eb.br

This work describes the determination of the shielding against ionizing radiation from atmospheric dispersion arising from

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

a radiological accident in a small nuclear reactor (SMR). Among the radionuclides from the inventory of this reactor, the contribution of Cs-137 was considered for simulation in HotSpot (analytical modeling) and ANSYS (numerical modeling), of the concentration and total effective doses (TEDE) received, both depending on the distance of the event. The analytical solution, based on the hypotheses of the Gaussian approach, aims to validate the numerical solution brought by the CFD techniques, in a simplified computational scenario, taking into account the set of partial differential equations that govern the physical phenomenon of the transport of this material radioactive. Additionally, for the analysis of shielding, Taylor's formulations were used to perform simple shielding calculations, considering only shelters, based on ordinary concrete, possibly existing in the contaminated area, and Broder, in multilaminated cases, with adding a layer of lead to the front of the wall. The relevance of this investigation shows the importance of planning responses in an emergency situation, considering the data assumed in the simulations. **Promotional text**: The present work can contribute to multilateral scientific cooperation, since the computational tools of this study can still be used in civil applications, such as the release of radionuclides from medical facilities, for example, and which use radioactive sources.

P2.4-307 – Spatial and Temporal Variation of the Anthropogenic Radionuclides Cs-137 and Cs-134 in Ground-Level Air Samples by IMS Stations Located on the African Continent

Author: Dorice Rashid Seif[1]
Co-author: Martin B. Kalinowski[2]
[1]*Tanzania Atomic Energy Commission (TAEC), Arusha, Tanzania*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: doricers85@gmail.com

Anthropogenic radionuclides of fission and activation products are frequently detected by most IMS stations located on the African continent with varying concentrations in the years 2011 to 2020. This study assesses the spatial and temporal variation of Cs-134 and Cs-137 in ground-level air at IMS stations located on the African continent from 2011 to 2020. Spatial and temporal base analysis will be performed to discern various patterns of these radionuclides. The study provides insight into the connection of anthropogenic radionuclide concentration levels in ground-level air with meteorological phenomena over the areas under investigations. It also discusses the results in view of the very few possible sources of anthropogenic radioactivity located in Africa, because for effective nuclear explosion monitoring it is important to understand the observed background. The African continent is rarely studied for this purpose and this presentation intends to fills that gap. **Promotional text**: For effective nuclear explosion monitoring it is important to understand the observed background of CTBT-relevant radionuclides. This presentation fills a gap by investigating the observations of Cs-137 and Cs-134 on the African continent.

P2.4-308 – Ultra-Sensitive Gamma Spectrometry Measurements of Environmental Samples from the Hartlepool Nuclear Power Station

Authors: Jonathan Burnett[1]; Ashley Davies[2]; Brian Milbrath[1]; Mark Arnold[3]; Craig Dohring[3]; Matthew Goodwin[2]; Allan Myers[1]; Andrew Petts[3]; Manish Sharma[1]; Michael Warren[3]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
[2]*AWE Aldermaston, Reading, United Kingdom*
[3]*EDF Energy, Hartlepool, United Kingdom*
Corresponding Author: jonathan.burnett@pnnl.gov

Two ultra-sensitive gamma-spectrometry systems are being used to measure environmental samples collected from the Hartlepool Nuclear Power Station in the United Kingdom. The work is being performed as part of the Xenon Environmental Nuclide Analysis at Hartlepool (XENAH) collaboration between Pacific Northwest National Laboratory (PNNL, USA), the Atomic

Weapons Establishment (AWE, UK) and EDF Energy (UK). The coincidence-based gamma-spectrometry systems are located at the Shallow Underground Laboratory (USA) and Boulby Underground Laboratory (UK), and they are being used to measure radionuclides that are relevant for nuclear explosion monitoring purposes. Stack filters for particulate fission and activation products, charcoal cartridges for gaseous iodine, and other environmental samples are being collected and measured. The advanced systems have detection sensitivities some orders of magnitude better than standard laboratory systems (e.g., for $^{106}Ru/^{106}Rh$, ^{134}Cs, ^{144}Ce), and they shall improve the understanding of the trace-level radionuclide emissions of the Advanced Gas-cooled Reactor (AGR) at Hartlepool. This is important for interpreting the radionuclide measurements performed at International Monitoring System (IMS) stations and determining whether detections are attributable to civilian nuclear sources or nuclear explosive tests.
Promotional text: These next-generation ultra-sensitive gamma-spectrometry systems are advancing the capabilities of the radionuclide laboratories and the understanding of background source terms, such as the Advanced Gas-cooled Reactor at Hartlepool, UK.

P2.4-335 – Effect of 2020 Chernobyl Exclusion Zone Wildfires on the IMS Radionuclide Station Network

Authors: Seokryung Yoon[1]; Jonathan Bare[1]; Jana Meresova[1]
Co-authors: Arend Harms[1]; Carla Pires[1]; Jun Wang[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: seokryung.yoon@ctbto.org

Wildfires broke out on the 3rd of April 2020 in the Chernobyl exclusion zone, and the fires lasted for several weeks. As a consequence, measurable amounts of Cs-137 were re-suspended into the atmosphere and observed through the IMS network. Over the period of April - May 2020, the International Data Centre reported a significant increase in the number of Cs-137 detections compared to the same period in the previous years. In this poster, all the stations from the IMS network that reported Cs-137 over the period into consideration are first given. Based on Atmospheric Transport Modelling (ATM) simulations, stations impacted by the plumes from Chernobyl were determined, and the effects of the wildfires were assessed through (1) measured activity concentrations of Cs-137 and (2) Cs-137-to-K-40 ratios. Finally, the impact of such natural events on the categorization of IDC products is also illustrated through the evolution of relevant discrimination thresholds.
Promotional text: This study demonstrates the capability of the CTBTO IMS network to track even very low activities of radionuclides in a large geographical area, which can provide opportunities and methods for improving nuclear test monitoring and verification.

P2.4-360 – NPE19 Source Term Reconstruction Based on Radionuclide Monitoring Result

Author: Yungang Zhao[1]
Co-authors: Xiaoming Wang[1]; Shilian Wang[1]; Jian Li[1]; Qi Li[1]; Xinjun Zhang[1]; Yuanqing Fan[1]; Huaimao Jia[1]
[1]*CTBT Beijing National Data Centre and Beijing Radionuclide Laboratory, Beijing, China*
Corresponding Author: yungang.zhao@nrl.org.cn

NDC Preparedness Exercises (NPE) are regularly performed to practice the verification procedures for the detections of nuclear explosions in the framework of CTBT monitoring. In the event of NPE-2019, a fictitious state RAETIA announced that a reactor had an incident and some radionuclides were released into the atmosphere. Both the IMS data and data from a fictitious neighbour state, EASTRIA, were provided to participants, and EASTRIA requested assistance from the IDC, called Expert Technical Analysis (ETA). The work we have done is radionuclide detections data analysis, ATM in backward mode by flexpart, source reconstruction in bayesian method.
Promotional text: In the event of NPE2019, some IMS radionulide stations measured some abnormal nuclides.

Based on these results, the work we have done is radionuclide detections data analysis, ATM in backward mode by flexpart, source reconstruction in bayesian method.

P2.4-373 – How Can We Determine the Origin of Radionuclide Observations? Presenting the Bayesian Source Reconstruction Algorithm "FREAR"

Author: Pieter De Meutter[1]
Co-authors: Ian Hoffman[2]; Kurt Ungar[2]
[1]*Belgian Nuclear Research Centre (SCK CEN), Mol, Belgium*
[2]*Radiation Protection Bureau, Health Canada, Ottawa, ON, Canada*
Corresponding Author: pieter.de.meutter@sckcen.be

Radionuclide observations made by the International Monitoring System are an important part of the CTBT verification regime, as it allows to discriminate between conventional and nuclear explosions. Atmospheric transport and dispersion modelling can link known sources with such observations. However, sometimes observations are made for which the source parameters (such as the release amount, release period and release location) are unknown. In that case, inverse atmospheric transport modelling can be used to determine the source parameters. In this talk, the Bayesian source reconstruction tool FREAR will be presented. The FREAR tool allows to determine source parameters based on radionuclide observations and source-receptor-sensitivities; the latter can be calculated by an atmospheric transport model and are routinely provided by the CTBTO. Detections and instrumental non-detections are taken into account, and the possibility of false alarms and misses is considered too. The Bayesian approach inherently takes into account uncertainties. Furthermore, a method to determine model uncertainties, based on an ensemble, will be presented.
Promotional text: An algorithm will be presented that determines the release location and other source parameters by making use of radionuclide observations (both detections and non-detections can be used) and atmospheric transport modelling. Uncertainties are rigorously taken into account.

P2.4-405 – Devices to Reduce the Emission of Radioactive Noble Gases into the Environment

Author: Eduardo Carlos Carranza[1]
[1]*Comisión Nacional de Energía Atómica de Argentina, Argentina*
Corresponding Author: edcarran2000@yahoo.com.ar

The Fission Radioisotope Production Plant of Argentina, located at the Ezeiza Atomic Center, produces ^{99}Mo since 1985 irradiating targets with High Enrichment Uranium. In 2002 the targets have been changed by Low Enrichment Uranium. Facilities that produce radioisotopes by fission increase the background of noble gases in the environment, especially radioactive xenon. This background could interfere with the CTBTO assessments of nuclear explosions. The work will show the production method for ^{99}Mo and ^{131}I that is carried out in Argentina, the emission levels and production during the last years. The current measurement system will also be described. Finally, different mechanisms for the reduction of noble gas emissions and a comparative study of the advantages and disadvantages of each of them will be presented.
Promotional text: The objective of the poster is to show which are the different alternatives for reducing noble gas emissions to the environment due to the production of radioisotopes by fission.

P2.4-421 – Characterization of Radioxenon Global Background Between 2015 and 2020

Author: Mohammed Yehia Taha Ahmed Elbahrawy[1]
Co-author: Sayed Mekhaimer[1]
[1]*National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Egypt*
Corresponding Author: m6yehia@yahoo.com

Worldwide monitoring of radioxenon is a necessary component of the International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The current IMS design foresees 40 radioxenon stations around the world to provide a 90% detectability of a 1 kt nuclear explosion within 14 days. Radioxenon stations have the capability to measure four radioxenon isotopes: ^{131m}Xe, ^{133}Xe, ^{133m}Xe, and ^{135}Xe. The discrimination between radioxenon emission from civil sources and xenon released from a nuclear explosion is achieved by analyzing different ratios between the four xenon isotopes. In the present work, we systematically study the development of the four Xe isotopes background between 2015 and 2020, and its geographical distribution according to the measurements from the IMS stations.

Promotional text: The Evolution of the four Xe isotopes background between 2015 and 2020 is analyzed, and its geographical distribution according to the measurements from the IMS stations is described.

P2.4-427 – Source-Term Estimation of the CTBT Relevant Radionuclides Using EgNDC-SRC and WEB-GRAPE Software

Author: Sayed Mekhaimer[1]
[1]*National Research Institute of Astronomy and Geophysics (NRIAG), Cairo, Egypt*
Corresponding Author: sayedmekhaimr@gmail.com

The source-term estimation of the radionuclides detected at IMS stations by using adjoint atmospheric transport modeling (ATM) is a vital part in the CTBTO monitoring and verification Regime. Webgrape software was developed by CTBTO International data center to assist the state signatories in the verification purposes of radionuclides detections. However, the source determination of an event and its nature is the state signatory's responsibility. Therefore, National Data Center of Egypt recently developed its own software for inverse modeling and source determination (EgNDC-SRC). The current work compares the source estimation algorithms of Webgrape and EgNDC-SRC by using some atmospheric transport modeling (ATM) synthetic experiments and some real events that have detections at IMS stations.

Promotional text: This work compares the source estimation of two software; the Webgrape and EgNDC-SRC, by using some ATM synthetic experiments and some real events that have radionuclide detections at IMS stations.

P2.4-461 – Modeling Plume Dispersion for Near Ground Explosion Scenarios in the Framework of a Decision Support System

Author: Alexander Hieden[1]
Co-authors: Kathrin Baumann-Stanzer[1]; Ulrike Mitterbauer[1]; Peter Mohr[2]
[1]*Central Institution for Meteorology and Geodynamics (ZAMG), Vienna, Austria*
[2]*Ministry of Defence, Vienna, Austria*
Corresponding Author: alexander.hieden@zamg.ac.at

The project ABC-MAUS is undertaken by a collaboration of the Austrian Ministry of Defense, Joanneum Research, the Austrian national weather and geophysical service Zentralanstalt für Meteorologie und Geodynamik (ZAMG), including the Austrian National Data Center (NDC), as well as the private company GIHMM. The aim is to develop a strategy of protection for chemical, biological, radiological and nuclear threats (CBRN) for the Austrian armed forces. Once the explosion is identified from infrasound and seismic measurements (reference to contribution by Mitterbauer et al.), forward modeling assuming a predefined release term is undertaken to understand which area might be contaminated. As soon as radiological measurements are available, the source term is adjusted. Tabletop-Exercises are developed and tested based on hypothetical near-ground explosion scenarios (ordinance, accidental or terror attack).

Promotional text: Atmospheric dispersion events with respect to radiological, biological and/or chemical materials.

P2.4-480 – Analysis of Atmospheric Radioxenon Detections in the UK

Authors: Matthew Goodwin[1]; Ashley Davies[1]; Richard Britton[2]
[1]*AWE Aldermaston, Reading, United Kingdom*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: matthew.goodwin@awe.co.uk

An IMS-like noble gas system is in operation at AWE (Aldermaston, UK) and can collect and measure the radioxenon content in environmental air samples. When operated in this mode, data produced is analysed at the UK National Data Centre (NDC) as part of the in-house radionuclide (RN) analysis pipeline. This work discusses a number of significant detection events analysed using the operational system deployed at the UK NDC, which includes atmospheric transport simulations and a real-time stack-monitoring data feed from a nearby medical isotope production facility in Belgium. A comparison of the expected radionuclide contributions with measured detections is presented, including a comparison of the isotopic ratios for the radioxenon isotopes of interest (Xe-133, Xe-131m, Xe-133m, Xe-135).

Promotional text: Radioxenon detections on an IMS-like SAUNA system operated at GBL15, the UK CTBT Radionuclide Laboratory, have been correlated with a medical isotope production facility in Europe.

P2.4-523 – Source Reconstruction from Dry and Wet Deposition Measurements

Authors: Max Schönlank[1]; Pieter De Meutter[1]; Johan Camps[1]; Andy Delcloo[2]; Piet Termonia[2]
[1]*Belgian Nuclear Research Centre (SCK CEN), Mol, Belgium*
[2]*Royal Meteorological Institute, Belgium*
Corresponding Author: max.schonlank@gmail.com

Measuring airborne radioactivity typically requires large, static installations, limited in number and geographical distribution. By measuring the activity of matter deposited to the ground (by dry settling or wet scavenging), one can complement detections of airborne activity and improve overall data availability. Many ways exist to detect deposited activity, such as using rain basins which capture precipitation for a known span of time, or directly sampling soil or bodies of water. The latter have certain drawbacks (e.g. ambiguity as to what timeframe of atmospheric activity is actually covered by the sample) leading to large uncertainties, but have the advantage that data can be gathered anywhere and at any time (including days or weeks after a plume of interest has already come and gone), without requiring any preexisting infrastructure. This presentation compares between atmospheric- and deposition-based detection as practical techniques by treating a series of cases simulating individual 'puff' releases. In every case, we determine how sensitive the existing network of International Monitoring System (IMS) stations would be to the release, and subsequently the surface area which a hypothetical rain collection basin would require at every location to match the sensitivity to the release that is achieved by the IMS stations.

Promotional text: Since radioactive particulates are subject to wet deposition and gravitational settling, we perform a modelling study to test whether deposition measurements can complement existing airborne measurements for source reconstruction purposes.

P2.4-551 – A Study of the Radioxenon Background and Potential Sources at IMS Station SEX63, Sweden

Authors: Mattias Aldener[1]; Tomas Fritioff[1]
[1]*Swedish Defence Research Agency (FOI), Stockholm, Sweden*
Corresponding Author: mattias.aldener@foi.se

Understanding the radioxenon background at the radionuclide stations in the IMS network is important to improve the verification capability of the network. The background at the IMS station SEX63 in Stockholm Sweden has been studied in the time period between 2012 to 2019 using data from the IMS SAUNA II system. From 2017 data have also been evaluated

from the co-located SAUNA III system. Xenon detections have been studied to understand potential sources and their contributions to the detections at the station. Detections have been characterized with respect to concentrations, isotopes detected and wind direction. ATM has been used to try to identify specific sources in a few case studies.
Promotional text: Understanding the radioxenon background at the radionuclide stations in the IMS network is important to improve the verification capability of the network. The background at the IMS station SEX63 has been studied between 2012 and 2019 and the results will be reported.

P2.4-552 – Preliminary Analysis Results of Ongoing Temporary Radioxenon Background Measurement Campaign in Japan

Author: Jonathan Bare[1]
Co-authors: Jana Meresova[1]; Abdelhakim Gheddou[1]; Martin B. Kalinowski[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: jonathan.bare@ctbto.org

In 2017, the Government of Japan has decided to make a voluntary contribution to further enhance the capabilities of the CTBTO verification regime. In that framework, two transportable noble gas systems were deployed in Horonobe and Mutsu. They respectively started operating in February 2018 and March 2018. Continued operation of the two systems is now financially supported with funding from European Union Council Decisions. Together with the IMS station RN38 in Takasaki, this forms a temporary high-density configuration network enabling observation of the same event release at different locations at distances of about 500 km from each other. As of today, few thousands of samples were already collected and measured in Mutsu and Horonobe, and this number is still increasing daily. Resulting spectra are automatically sent to the IDC and processed in a non-operational database. They are routinely reviewed, and the concentrations of the four xenon isotopes of interest for the CTBTO (^{131m}Xe, ^{133m}Xe, ^{133}Xe and ^{135}Xe) are calculated. Analysis results are made available (together with raw data) to State Signatories through a Secure Web Portal. In this work, preliminary analysis results of ongoing temporary background measurement campaigns are presented.
Promotional text: Preliminary analysis results of ongoing temporary background measurement campaigns in Japan are presented in this e-poster.

P2.4-553 – Subsoil Measurements in Sweden of Radioxenon and Radioargon

Authors: Mattias Aldener[1]; Tomas Fritioff[1]; Anders Axelsson[1]; Klas Elmgren[1]; Lindsay Karlkvist[1]; Johan Kastlander[1]; Catharina Söderström[1]; Henrik Olsson[1]; Anders Ringbom[1]; Roland Purtschert[2]
[1]*Swedish Defence Research Agency (FOI), Stockholm, Sweden*
[2]*University of Bern, Switzerland*
Corresponding Author: mattias.aldener@foi.se

The most important indicators for an underground nuclear explosion during a CTBT on-site inspection are the radioactive xenon isotopes ^{131m}Xe, ^{133}Xe and ^{133m}Xe and the radioactive argon isotope ^{37}Ar. Knowledge of how these isotopes vary and potentially correlate in different types of soil is essential to be able to discriminate between the natural background and a signal from a nuclear explosion. A series of measurements has been performed at different depths within a limited area in the region of Kvarntorp (Sweden), a location with known elevated uranium content in the ground. To investigate variations of the naturally occurring noble gas concentration in sub soil gas over time and at different depths sub soil sample collection was carried out over a period of two weeks. The analytical results from the collected samples will be discussed in relation to radon levels, soil uranium content and environmental parameters such as the meteorological conditions.
Promotional text: Radioactive noble gases are important indicators of a underground nuclear explosion. To investigate

variations of the naturally occurring noble gas concentration in sub soil gas over time sub soil sample collection was carried out over a period of two weeks.

P2.4-563 – Simulating Xe-133 Concentrations at IMS Noble Gas Stations, Using Operational Stack Emission Data from the Medical Isotope Production Facility of Fleurus

Authors: Andy Delcloo[1]; Pieter De Meutter[2]; Anas Hamdouchi[3]; Benoît Deconninck[3]
[1]*Royal Meteorological Institute, Belgium*
[2]*Belgian Nuclear Research Centre (SCK CEN), Mol, Belgium*
[3]*Institute for Radio-Element, Fleurus, Belgium*
Corresponding Author: andy.delcloo@meteo.be

The National Institute For Radioelements (IRE), located at Fleurus in Belgium, is an important emitter of radioactive xenon into the atmosphere. These emissions are not harmful to the environment, but can interfere with the very sensitive noble gas detection stations that are part of the verification regime of the Comprehensive Nuclear-Test-Ban Treaty Organization. Radioxenon stack emission data from civilian nuclear facilities, combined with atmospheric transport modelling, can help to discriminate real events (radioactive xenon detections that originate from a nuclear explosion) from false alarms (radioactive xenon detections that originate from a civilian nuclear facility). In this presentation, we will present the additive value of using the STAX data from the Fleurus site in near real time xenon forecasts in order to show its capability to model the radioactive xenon background on the CTBTO noble gas stations. We will use the Lagrangian particle dispersion model Flexpart to calculate the transport and dispersion of Xe-133, using numerical weather prediction data from the European Centre for Medium-Range Weather Forecasts. Radioxenon activity concentration time series will be presented. The results will be compared with observations of the International Monitoring System and statistical scores will be calculated.

Promotional text: The simulation of Xenon-133 in near real-time, using STAX data, will improve our understanding of the xenon background in an operational context.

P2.4-590 – Evaluating the Added Value of Multi-Input Atmospheric Transport Ensemble Modelling for Applications of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)

Authors: Christian Maurer[1]; Delia Arnold Arias[1]; Jerome Brioude[2]; Magdalena Haselsteiner[1]; Florian Weidle[1]; Leopold Haimberger[3]; Paul Skomorowski[1]; Pierre Bourgouin[4]
[1]*Central Institution for Meteorology and Geodynamics (ZAMG), Vienna, Austria*
[2]*Atmosphere and Cyclone Lab (LACy), University de La Reunion, France*
[3]*University of Vienna, Vienna, Austria*
[4]*Former CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: christian.maurer@zamg.ac.at

The potential benefit of ensemble dispersion modeling for CTBTO applications was investigated using input data from the ECMWF-Ensemble Prediction System (EPS). Five different test cases – among which are the ETEX-I experiment and the Fukushima accident - were run. For those test cases run in backward mode and based on a puff release it became evident that Probable Source Regions (PSRs) can be reduced in size compared to results based solely on the deterministic run by applying minimum and probability of exceedance ensemble metrics. It was further demonstrated that a given puff release can be reproduced within the meteorological uncertainty range. For the test cases run in forward mode it was found that the control run, 10- and 51-member medians exhibit similar performance in time series evaluation. The main added value of the forward ensemble lies in producing meteorologically induced concentration uncertainties and thus explaining observed measurements at specific sites. It can be concluded that meteorological uncertainty to a large degree is covered by

the 10-member subset because forecast uncertainty is largely suppressed due to concatenating analyses and short term forecasts, as required in the operational CTBTO procedure, and because members from different analyses times are on average unrelated.
Promotional text: Enhance the capabilities of the Treaty's verification regime via ensemble dispersion modeling.

P2.4-606 – Global Radioxenon Emission Inventory 2014 from All Types of Nuclear Facilities

Author: Martin B. Kalinowski[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: martin.kalinowski@ctbto.org

The goal of the third ATM challenge is to perform atmospheric transport modelling in order to estimate radioxenon observations at selected IMS stations in the northern hemisphere for an extended period in the year 2014 (June to November). This estimation is needed for calibration and performance assessment of the verification system as described in the Treaty. The best estimates for Xe-133 emissions from known sources is used as input data for this exercise. This presentation summarizes the global radioxenon emissions inventory for the whole year 2014. It comprises all relevant nuclear facilities. For the two strong sources IRE (Belgium) and CRL (Canada) stack release data with a high time resolution are available. For nuclear power plants (NPP) in Europe and the USA the reported release for the whole year are applied in combination with information about their operational schedule. For all other NPPs and for the strongest research reactors sources the best estimates are used. The estimated release of the strongest nuclear research reactors sources is included as well as the annual emissions from the Mallinckrodt facility (The Netherlands), the NIIAR facility (Russia) and the Karpov Institute (Russia).
Promotional text: This presentation summarizes the best estimates of radioxenon emissions from all nuclear facilities in the year 2014. It is a unique data set to be used in studies to enhance data analysis from the noble gas component of the International Monitoring System.

P2.4-607 – Investigation of Xe-135 Observations at IMS Noble Gas Systems Generated by Neutron Activation and Its Relevance for Nuclear Explosion Monitoring

Author: Martin B. Kalinowski[1]
Co-authors: Jolanta Kusmierczyk-Michulec[1]; Boxue Liu[1]; Anne Tipka[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: martin.kalinowski@ctbto.org

Strong neutron sources may generate significant amounts of radioxenon by activation of stable xenon. Radioxenon emission from some nuclear research reactors and from spallation neutron sources are dominated by neutron activation as the production process. The isotopic ratios are different from fission gases. Activation generates Xe-135 to Xe-133 activity ratios like fission but the activated gases may escape from the facility faster than fission products that are initially contained within fuel cladding. Therefore, less Xe-135 has decayed and a comparatively higher activity is emitted. When detected at an IMS station, the Xe-135 to Xe-133 activity ratio can even exceed the threshold for raising the screening flag that indicates it appears like a prompt release from a nuclear explosion. It may also happen that Xe-135 is observed without simultaneous detection of Xe-133 in the same sample. This presentation investigates activation sources that could possibly be observed at IMS sites. These include the HFIR reactor and strong spallation neutron sources. The conclusions of this study have important implications for assisting States in identifying the source of a specific event and for the decision whether interference corrections for non-traditional radioxenon isotopes generated by activation needs to be introduced to the operational software.
Promotional text: This presentation investigates whether

radioxenon generated by activation may be observed by IMS noble gas systems. This is important for Expert Technical Analysis and possibly for making IDC software robust against interference from non-traditional radioxenon isotopes.

P2.4-637 – How to Use the FLEXPART Model in Atmospheric Transport Modelling Challenges

Author: Petra Seibert[1]
[1]*University of Vienna, Austria*
Corresponding Author: petra.seibert@univie.ac.at

The "Flexible Lagrangian particle dispersion model" FLEXPART is used in the IDC as well as by many of the participants in the Atmospheric Transport Modelling Challenges. As a truly flexible model, it may be used in forward and backward mode and it has many other parameters that can be set by users. All of these options influence the CPU and memory requirements as well as the accuracy of the output. For example, if we consider only a small number of stations and daily or half-daily samples, but are interested in a large number of possible emitters and/or emission time slots, backward simulations will usually be more efficient. There is also the option of using gridded output or a point receptor with a sampling kernel. Number of particles and model time steps also influence both the resources required and the results. For the ATM Challenge 3, certain modifications have been implemented in FLEXPART version 10 to make full use of possible combinations of options. Pertinent findings and recommendations will be reported.
Promotional text: FLEXPART users will be assisted to better understand the options for organizing and setting up simulations for complex or compute-intensive tasks. ATM challenge 3 will be used to compare options, derive recommendations, and make trade-offs involved more transparent.

T2.5 Historical Data from Nuclear-Test Monitoring

Highlights

Seismic Data

O2.5-298 described the seismic data catalogue on 47 nuclear tests conducted at the Lop Nor site in China between 1964 and 1996, including 3 surface, 19 atmospheric and 25 underground tests. A catalogue and bulletin were created using the archived seismograms of Central Asian stations located in Kazakhstan, Kyrgyzstan and the Russian Federation (epicentral distance 700-2500 km). Using satellite imagery, epicentres were determined for all explosions, including atmospheric and small underground tests. Many of the explosions can be used as ground truth events to construct regional seismic travel time curves and for station calibration. P2.5-297 presented travel time curves based on the seismograms of the Lop Nor tests for regional phases Pn, Pg, Sn, Sg and LR.

The Soviet Union detonated 122 peaceful nuclear explosions (PNEs) from the mid-1960s through the late 1980s. The PNEs were conducted in a wide range of geological settings and geographical locations, thus representing a unique data set for geophysical studies. P2.5-594 and P2.5-499 described the recovery and digitization of seismograms from these PNEs. Most are from short-period instruments and, when properly combined with calibration information, can recover ground motion signals to at least 5 Hz. PNEs can be modelled as point sources, and because the source characteristics are known, they serve as ground truth events. The amplitude spectral ratios are tested as discrimination criteria.

P2.5-176 described the large chemical explosions conducted in Kazakhstan during Soviet times. The parameters of these explosions are known and can be used as ground truth events

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP
SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

for the calibration of regional seismic networks in Central Asia. In addition, on the territory of the Semipalatinsk Test Site there were 175 chemical explosions conducted for military and scientific purposes; the parameters are known for approximately 30 explosions.

P2.5-443 described how the digitization process of legacy seismograms was improved by applying an interpolation algorithm and examining the frequency recovery of the potential records. Preliminary results indicate that a 200 DPI image can recover signals up to about 2.5 Hz, whereas a 600 DPI image can recover up to about 8 Hz, assuming an original recording speed of 60 mm/s and a short period sensor. P2.5-397 described applying calibration to digitized historical seismograms. Software was developed to convert the originally published yearly station calibration parameters into seed files, focusing on stations and instrumentation from the former Soviet Union. Comparison of the power spectral density measurements of digitized SKM short period analog records against co-located digital broadband instruments has demonstrated accurate prediction of ground motion in the range of 0.3 Hz to 5 Hz.

P2.5-086 and P2.5-089 reported on the creation of a unified seismic bulletin of Central Asia, using earthquake data from 1949–2009. Analog seismograms were converted into digital format. The unified bulletin contains over 10 million arrivals, with preliminary relocation of more than 350,000 events. To obtain regional magnitude conversion relationships from small events with traditional magnitudes (ML, mb and Ms), the authors used a coda calibration technique that allows direct calculation of Mw from source spectra. When data ingestion and relocation are finalized, the result will provide a basis for many other studies (e.g. travel time tomography, seismicity) that have not been previously possible. P2.5-092 provided a reliable seismicity map that can be used in a probabilistic seismic hazard analysis for Georgia. The relocation results of more than 20,000 events were presented in the bulletin.

P2.5-181 discussed the Borovoye Geophysical Observatory in Kazakhstan, which celebrated its 70th anniversary in 2021. The observatory has provided continuous digital data since 1966. In 1974, the Vostochnoye, Chkalovo and Zerenda seismic stations were installed near the observatory and formed a large-aperture triangle array, with the observatory as the central station. The magnetotelluric and infrasound stations were also used for monitoring. Auxiliary seismic station AS57 was constructed at the observatory area and certified in 2002.

Radionuclides

O2.5-481 presented a literature review on atmospheric radionuclide monitoring, covering 35 nuclear tests conducted between 1964 and 1996. Most of these tests occurred in the atmosphere, but nuclear debris from venting of underground nuclear tests was also observed. The review is limited to off-site monitoring, and many observations were done at large distances. Twenty-eight per cent of the tests were observed at two different locations, and 16 per cent were reported from three or more monitoring locations. Wet and dry deposited radioactivity was historically a major method. One third of all papers report about gamma spectroscopy of particulate filters, and almost 10 per cent address noble gas measurements.

P2.5-712 described the study of radioactivity in the annually laminated sediments deposited in Lake Kevojärvi, Finland. The freeze cores preserve a distinct succession of annual laminations deposited between 1909 and 2015. A total of 53 annual laminations were taken for gamma spectroscopic measurements using low-background gamma spectroscopy. This allowed a reconstruction of caesium, americium and lead fallout history. Caesium concentrations were first found to increase in 1956 and peaked in 1964, 1970 and 1986. Americium concentrations peaked in slightly different years. A two year delay was observed between intensive nuclear-weapons testing and peaks in the sediment records.

Photography

O2.5-173 described how film footage of historical nuclear tests enables new analysis of the shock propagation and buoyant cloud rise with material entrainment. Many films of late clouds were captured from at least two positions, enabling accurate characterization of the cloud development and trajectory. The authors presented the use of historical film to provide many types of data to validate and improve models of late cloud behaviour. Combining such data with an understanding of buoyant cloud rise and cloud stabilization informs entrainment, including the total mass of entrained materials.

O2.5 Historical Data from Nuclear-Test Monitoring Abstracts of Oral Presentations

O2.5-173 – Using Historical Data to Improve Analysis of Nuclear Testing

Author: Stephanie Neuscamman[1]
Co-authors: Greg Spriggs[1]; Kim Knight[1]; Lee Glascoe[1]
[1]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: neuscamman1@llnl.gov

Films from historic nuclear testing enable new analysis of the shock propagation and buoyant cloud rise with material entrainment, furthering understanding of the time-evolution of the entrained mass. Many late cloud films were captured from at least two positions, enabling accurate characterization of the cloud development and trajectory. A generalized framework is developed to capture the similarity of nuclear debris cloud formation for detonations with similar scaled heights of burst. The nuclear debris cloud regimes are defined based on debris cloud behavior observed in a dry, dusty environment with loose, easily lofted surface material and can be used to improve dispersion models. As new information on how expected material entrainment and mixing is affected by the surrounding environment becomes available, adjustments to the regime height-of-burst ranges are easy to adopt. Both fast-running fallout codes and higher-fidelity cloud-rise and fallout codes need to be validated against existing test data. We present on the use of historical film to provide many types of data to validate and improve models of late cloud behavior. Combining such data with an understanding of buoyant cloud rise and cloud stabilization informs entrainment including the total mass of entrained materials.

Promotional text: The historic test films inform a generalized framework to understand nuclear debris clouds. New analysis of film data furthers the source characterization of nuclear detonations and provides accurate validation data sets for predictive fallout models.

O2.5-298 – Analysis of Historical Seismograms of Central Asia Stations to Précise the Parameters of Nuclear Tests at Lop Nor Test Site

Author: Inna Sokolova[1]
Co-authors: Kevin Mackey[2]; Alexander Velikanov[1]; Irina Aristova[1]
[1]*Institute of Geophysical Research, Almaty, Kazakhstan*
[2]*Michigan State University (MSU), East Lansing, MI, USA*
Corresponding Author: sokolova@kndc.kz

The Lop Nor Test Site is located in Xinjiang Province in the Peoples Republic of China, about 600 km away of Kazakhstan. From 1964-1996, there were 47 nuclear tests, including 3 surface, 19 atmospheric, and 25 underground. During this time, the U.S. operated monitoring networks of sensitive seismic stations having both analog and digital instruments. A seismic catalog and bulletin was created using the archived seismograms of Central Asian stations located in Kazakhstan, Kyrgyzstan, and Russia (epicentral distance 700-2500 km). In total, 800 seismograms of 41 explosions were processed. Using satellite imagery, epicenters were précised for all explosions, including atmospheric and small underground tests. The mb, regional mpv and MLV magnitudes, and energy class K were calculated. The waveforms of Lop Nor air and surface explosions were analyzed using microbarograph records from the Talgar Observatory in Kazakhstan. For several small explosions, locations were précised, dynamic parameters of seismic and infrasound records were analyzed, and origin times were calculated for the first time. As a result, the précised catalogue of nuclear explosions conducted at Lop Nor Test Site was compiled. Many of the explosions can be used as Ground Truth events to construct the regional travel-time curves and for stations calibration.

Promotional text: The precise catalogue of nuclear explosions conducted at Lop Nor Test Site was compiled.

O2.5-481 – Overview on Historic Atmospheric Radionuclide Monitoring Data Associated with Nuclear Test Explosions Conducted between 1964 and 1996

Author: Martin B. Kalinowski[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: martin.kalinowski@ctbto.org

A literature review is presented on historic atmospheric radionuclide monitoring data that were associated with nuclear test explosions. It covers reports related to tests conducted between 1964 and 1996. Most of these tests occurred in the atmosphere but observation of nuclear debris from venting of underground nuclear tests was also found. The review is limited to off-site monitoring and many observations were done at large distances including several tests that were detected on multiple locations on the same hemisphere. This data set could be of value for validating methods based on atmospheric transport simulations with the objective of identifying the source of an event that is of relevance for atmospheric radioactivity monitoring for the Comprehensive-Nuclear-Test Ban Treaty.

Promotional text: The unlifted treasure of historic radionuclide observations associated with nuclear test explosions could be valuable for realistic case studies demonstrating the performance of methods for identifying the source of an event that is of relevance for CTBT radioactivity monitoring.

P2.5 Historical Data from Nuclear-Test Monitoring Abstracts of Poster Presentations

P2.5-086 – A Comprehensive Earthquake Catalogue in Central Asia

Author: Istvan Bondar[1]
Co-authors: Barbara Czecze[2]; Kevin Mackey[3]; Kenneth Abrams[3]; Anna Berezina[4]; Natalya Mikhailova[5]; Rengin Gok[6]
[1]*Research Centre for Astronomy and Earth Sciences, Budapest, Hungary*
[2]*Eotvos Lorand University, Budapest, Hungary*
[3]*Michigan State University (MSU), East Lansing, MI, USA*
[4]*Institute of Seismology, National Academy of Science, Bishkek, Kyrgyzstan*
[5]*Institute of Geophysical Research, Almaty, Kazakhstan*
[6]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: ibondar2014@gmail.com

The Lawrence Livermore National Laboratory (LLNL), Michigan State University (MSU), and national data centers in Central Asia (Kazakhstan, Kyrgyzstan and Tajikistan) digitized analog seismic bulletins in order to produce a new, unified seismic catalog. The main objective of the project is to provide a reliable seismicity map for new probabilistic seismic hazard analysis of Central Asia. The national network bulletin data are supplemented by data from the International Seismological Centre (ISC) bulletin. We present the preliminary relocation results of more than 350,000 events recorded by hundreds of seismic stations in the region. Digitized bulletins extend to the early 1950s, providing millions of amplitude and phase arrival data. We relocated each event with iLoc, a single event location algorithm, using both ak135 and Regional Seismic Travel Time

(RSTT) predictions to improve locations and to measure the performance of the RSTT model. The results show significant improvements in the understanding of regional seismicity in Central Asia. When data ingestion and relocation are finalized, the result will provide a basis for many other studies (e.g., travel-time tomography, seismicity) that have not been previously possible.
Promotional text: Strengthen the engagement of the scientific communities working in test ban monitoring. As a result of exchange of data from diverse institutions we improve the earthquake locations and earth models in Central Asia.

P2.5-089 – A Unified Seismic Bulletin of Central Asia Using Legacy Data

Author: Anna Berezina[1]
Co-authors: Natalya Mikhailova[2]; Kevin Mackey[3]; Inna Sokolova[2]; Bayan Bekturganova[4]; Shohrukh Murodkulov[5]; Elena Pershina[6]; Kenneth Abrams[3]; Rengin Gok[7]
[1]*Institute of Seismology, National Academy of Science, Bishkek, Kyrgyzstan*
[2]*Institute of Geophysical Research, Almaty, Kazakhstan*
[3]*Michigan State University (MSU), East Lansing, MI, USA*
[4]*Seismological Experimental and Methodological Expedition, Almaty, Kazakhstan*
[5]*Institute of Geology, Earthquake Engineering and Seismology of NAS, Dushanbe, Tajikistan*
[6]*Institute of Seismology, National Academy of Science (IS NAS KR), Bishkek, Kyrgyzstan*
[7]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: annaberezina8@gmail.com

We have created a unified seismic bulletin of Central Asia to improve event locations and knowledge of seismic hazards. The national data centers and seismic networks of Kazakhstan, Kyrgyzstan, and Tajikistan have digitized paper historic bulletins of earthquakes with mb3.0 and greater from this region of Eurasia for 1949-2009. Soviet-era data covering portions of Uzbekistan, Turkmenistan, and Russia are included for completeness. Data from the International Seismological Centre (ISC) for all years, and local digital seismic bulletins since 1993, were collected and merged with the digitized bulletins. The unified bulletin contains over 10 million arrivals. To obtain regional magnitude conversion relationships from small events with traditional magnitudes (ML, mb, and Ms), we use a coda calibration technique that allows direct calculation of Mw from source spectra obtained using the Coda Calibration Tool (CCT), which was developed at Lawrence Livermore National Laboratory (LLNL). After merging all available information and relocations, the unified seismic bulletin was created. This is the first comprehensive bulletin developed for this region. This project fills in a considerable portion of a gap for the region, increases the accuracy of event parameters, preserves unique, perishable archival data, and supplements ISC bulletins with new data for the region.
Promotional text: Strengthen the engagement of the scientific communities working in test ban monitoring. As a result of exchange of data from multi-country institutions we improve the earthquake source parameters and locations and earth models in Central Asia.

P2.5-092 – Seismicity of the Caucasus Region: A Comprehensive, Revised Catalogue for 1951–2019

Author: Barbara Czecze[1]
Co-authors: Istvan Bondar[2]; Tea Godoladze[3]; Gurban Yetirmishli[4]; Rengin Gok[5]
[1]*Eotvos Lorand University, Budapest, Hungary*
[2]*Research Centre for Astronomy and Earth Sciences, Budapest, Hungary*
[3]*Institute of Earth Sciences and National Seismic of Georgia Center, Ilia State University, Tbilisi, Georgia*
[4]*Republic Seismic Survey Center of ANAS, Baku, Azerbaijan*
[5]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: czecze.barbara@gmail.com

The Lawrence Livermore National Laboratory (LLNL) and the Institute of Earth Sciences (IES), Ilia State University developed a project to generate a new seismic catalog for Georgia. The main objective of the project was to provide a reliable seismicity map that can be effectively used in a new probabilistic seismic hazard analysis for Georgia. Monitoring centers in Armenia and Turkey have also contributed bulletins from their own archives and provided picks for selected events. A subset of events from the IES bulletin was used as an input for the seismic hazard analysis. This data set is combined with the seismological bulletins of the Republic Seismic Survey Center (RSSC) and the International Seismological Centre (ISC) bulletin. We present the relocation results of more than 20,000 events in the bulletin. We relocated each event with iLoc, a single event location algorithm, using Regional Seismic Travel Time (RSTT) predictions to improve locations. Using the iLoc results as initial locations, we then applied Bayesloc, a multiple event location algorithm, to simultaneously relocate the entire seismicity of the Caucasus region. The results show significant improvements in the understanding of regional seismicity.
Promotional text: Strengthen the engagement of the scientific communities working in test ban monitoring. As a result of the contribution of this large dataset, regional earth models will be improved which will reduce the uncertainties in regional discrimination studies.

P2.5-176 – Large Chemical Explosions of the Soviet Period on the Territory of Kazakhstan as Ground Truth Events

Authors: Inna Sokolova[1]; Irina Aristova[1]; Darkhan Komekbayev[1]; Alexander Velikanov[1]
[1]*Institute of Geophysical Research, Almaty, Kazakhstan*
Corresponding Author: sokolova@kndc.kz

In Soviet times, large chemical explosions were conducted on the territory of Kazakhstan with different purposes (industrial, investigative, military). The parameters of these explosions are quite well known, but can be further elaborated by special investigations using contemporary methods. Furthermore, these explosions can be used as ground-truth events for the calibration of regional seismic networks in Central Asia. These explosions are: (1) investigative explosions in the south of Kazakhstan, Arys 19.12.1957, yield 1000t; (2) double explosions for construction of a mud dam near Almaty: Medeo 21.10.1966, (1689t and 3604t) and Medeo 14.04.1967 (3940 and 1944t); (3) investigative explosion "Massa" near Almaty, 28.11.1981 (251t); (4) investigative explosions in Central Kazakhstan of 9 ton yield Chemex-1 2.09.1987, Chemex-2 3.09.1987. In addition, on the territory of Semipalatinsk Test Site there were 175 chemical explosions conducted for military and scientific purposes; the parameters are known for ~30 explosions. For these explosions, using the archive and published data, the source parameters were specified, the catalogue and seismic bulletin were compiled. The kinematic and dynamic parameters of records were investigated, regional travel-time curves were constructed. The seismic effect of the investigated explosions was compared with that of other large chemical explosions conducted in Central Asia.
Promotional text: We collected information about large

chemical explosions were conducted on the territory of Kazakhstan. These explosions can be used as ground-truth events for the calibration of regional seismic networks in Central Asia.

P2.5-181 – 70 Year Contribution of Borovoye Geophysical Observatory to Nuclear Explosion Monitoring

Authors: Dilyara Bekbulatova[1]; Natalya Mikhailova[1]; Inna Sokolova[1]; Vadim An[2]
[1]*Institute of Geophysical Research, Almaty, Kazakhstan*
[2]*Institute of Dynamics of Geosphere, Russian Academy of Science (RAS), Moscow, Russian Federation*
Corresponding Author: dilyara@kndc.kz

2021 is 70-years from the day when nuclear explosion of 38 Kt yield was conducted at STS and recorded at Borovoye area. Following first successful experiment and field works, the Special Division of IPE U.S. decided to establish "Borovoye" geophysical observatory. In 1961, it recorded UNE of 2.6 Kt from Nevada Test Site at ~10 thousand km distance. "Borovoye" Observatory is one of the most known global stations for nuclear explosions monitoring. Its uniqueness is determined by good seismological-geological settings for seismic signals recording, the most continuous history of digital recording started in 1966. In 1974, Vostochnoye, Chkalovo, and Zerenda seismic stations were installed near the Observatory, and formed a so-called large-aperture "Triangle" array with the central station on the Observatory territory. In different years, the magnetotelluric and infrasound stations were used here for monitoring. In the post-Soviet period, BVAR seismic array of the IMS was constructed at the Observatory area and certified in 2002; in addition, BORK seismic station of IRIS IDA was installed here. The report presents the history of Borovoye Observatory, shows the examples of recorded nuclear explosions conducted at different world Test Sites, and investigates the spectral density of seismic noise in different periods of time.

Promotional text: The report shows the history of establishing of "Borovoye" Geophysical Observatory that this year celebrates its 70-years of operation and invaluable contribution into the nuclear explosions monitoring. In addition, the station has the longest period of digital observations.

P2.5-297 – The Travel-Time Curve for the Region of the East Tien Shan by the Records of Historical Seismograms of Underground Nuclear Explosions from the Lop Nor Test Site Area

Author: Irina Aristova[1]
Co-authors: Inna Sokolova[1]; Kevin Mackey[2]
[1]*Institute of Geophysical Research, Almaty, Kazakhstan*
[2]*Michigan State University (MSU), East Lansing, MI, USA*
Corresponding Author: i.aristova@kndc.kz

We constructed travel-time curves for eastern Tien-Shan using historical seismograms of underground nuclear explosions from the Lop Nor test site in the People's Republic of China. We measured the arrival times of the main seismic phases on seismograms from 1969-1996 stored in the analog archives of Kazakhstan as well as digital stations from Kazakhstan and Kyrgyzstan. In total, more than 500 seismograms were processed. The data were used to construct travel-time curves for regional phases Pn, Pg, Sn, Sg, and LR at distances ranging from 700 to 2500 km. Individual travel-time curves were constructed for each event for which the nature of each wave group was précised; a joint averaged travel-time curve for east Tien-Shan using all events was also constructed. The construction of the travel-time curve is used for such tasks as precision of the main parameters of explosions at Lop Nor, improvement of location accuracy of seismic events sources from the east Tien-Shan region (including Lop Nor Test Site area), and other tasks. The travel-time curve for the eastern Tien-Shan was compared to one in routine use for Central Kazakhstan that was calculated using regional chemical calibration and nuclear explosions conducted on the territory of Semipalatinsk Test Site.

Promotional text: We constructed travel-time curves for eastern Tien-Shan using historical seismograms of underground nuclear explosions from the Lop Nor test site.

P2.5-397 – Applying Calibrations to Digitized Historical Analog Seismograms of Nuclear Explosions and Other Important Events

Author: Daniel Burk[1]
Co-author: Kevin Mackey[1]
[1]*Michigan State University (MSU), East Lansing, MI, USA*
Corresponding Author: burkdani@msu.edu

Digitization of analog seismograms from past nuclear tests are critical for monitoring because many historical tests occur within unique geologic environments. To utilize this digitized data, it is important to know the frequency characteristics of the seismic channel that generated the seismogram to accurately correct for instrument response and recover ground motion. Calibrations can vary significantly with time and location, thus a single generic calibration for a station or instrument type is insufficient. Focusing on stations and instrumentation from the former Soviet Union, we developed software to accurately translate the original published yearly station calibration parameters into modern dataless SEED files. We compare Power Spectral Density (PSD) measurements of digitized SKM short-period analog records against co-located digital broadband instruments to demonstrate that the process yields an accurate picture of ground motion from 0.3-5 Hz. The resulting transformation of the digitized analog seismogram into a faithful digital rendering of ground motion can be used for advanced seismic analysis, including waveform transformation between displacement to velocity domains, frequency-based discrimination studies, and more. We are now applying the correct station calibrations to several seismogram recovery and digitization projects in northern Eurasia.

Promotional text: Historical seismograms, when accurately digitized, also require a modern description of channel response. We have developed techniques to translate historical calibration parameters and metadata into modern response files that correct for channel response to yield ground motion.

P2.5-443 – Producing High Quality Digitizations from Historical Analog Seismograms of Nuclear Explosions

Author: Kaitlynn Burkhard[1]
Co-authors: Daniel Burk[1]; Kevin Mackey[1]
[1]*Michigan State University (MSU), East Lansing, MI, USA*
Corresponding Author: burkha81@msu.edu

The recovery and digitization of legacy seismogram waveforms is critical for research of historical events in nuclear monitoring. We are improving the digitization process by applying an interpolation algorithm and examining the frequency recovery of the potential records. The implementation of a Piecewise Cubic Hermite Interpolating Polynomial (PCHIP) interpolation algorithm improves the quality of the digitization and minimizes the amount of distortion. We quantify the effectiveness of scan density by the ease of digitization and waveform accuracy. Low scan resolutions adversely affect waveform accuracy and ultimately the frequency recovery. This is demonstrated in a synthetic 'white noise' seismogram that emulates an analog record. The synthetic signal is converted to numerous scan resolutions then digitized. After digitization, the digital seismograms are compared back to the original synthetic seismogram. Preliminary results indicate that a 200 DPI image can recover signals up to about 2.5 Hz whereas a 600 DPI image can recover up to about 8 Hz, assuming an original recording speed of 60 mm/s and a short period sensor. Additional analog seismogram parameters such as line width, signal contrast, and signal amplitude all factor into the overall quality and waveform accuracy of digitized data.

Promotional text: We have improved the digitization process for analog seismograms representing historical nuclear explosions and quantified the effects of variables such as scan resolution, contrast, and line thickness and how they impact waveform accuracy, and ultimately frequency recovery.

P2.5-499 – Quantitative Research Using Digitized Historic Short-Period Nuclear Explosion Seismograms

Authors: Luis Bernardo Martinetti[1]; Josie Anderson[1]
Co-authors: Kevin Mackey[1]; Hans Hartse[1]
[1]*Michigan State University (MSU), East Lansing, MI, USA*
Corresponding Author: martinet@msu.edu

The recovery and digitization of Peaceful Nuclear Explosions (PNEs) from the Soviet Era provides a unique opportunity to study the geology and geophysics of seismically quiescent regions. Due to the improved digitization and excellent recovery of the analog signals, these now-digital seismograms can be used with modern seismic modeling techniques. PNEs can be modeled as point sources and since the source characteristics are known, they serve as ground truth events. However, regional geology heavily affects the ability to distinguish between nuclear explosions and tectonic earthquakes, such as in the Siberian Platform. We are using regional full moment tensor inversions of the digitized PNE data to see if it can be used to compare competing Earth models of these regions, since we know the nature of the source of the events. We also evaluate amplitude data in multiple frequency bands to find phase-based discrimination criteria in relation to the local geology in regions of northern Eurasia. Furthermore, the moment tensors and phase ratios can be researched with respect to how the emplacement geology, regional stress, depth, and yield affect the seismic signal. Other abstracts describe the data set and digitization process.

Promotional text: The applicability of short-period digitized seismic data from Soviet Era Peaceful Nuclear Explosions are tested through evaluation of source characteristics and event discrimination.

P2.5-594 – Digitization of Soviet Peaceful Nuclear Explosion Seismograms

Authors: Alexei Malovichko[1]; Yuri Vinogradov[1]; Ruslan Dyagilev[1]; Pavel Butyrin[1]; Kevin Mackey[2]; Daniel Burk[2]; Kaitlynn Burkhard[2]; Chris Witte[2]; Brandi Wheeler[2]; Anna Dobrynina[3]
[1]*Geophysical Survey, Russian Academy of Sciences, Russian Federation*
[2]*Michigan State University (MSU), East Lansing, MI, USA*
[3]*Institute of the Earth's Crust, Siberian Branch of the Russian Academy of Science, Russian Federation*
Corresponding Author: mackeyke@msu.edu

The Geophysical Survey of the Russian Academy of Sciences and Michigan State University are working to recover, preserve, scan, and digitize the historic seismograms of Soviet Peaceful Nuclear Explosions (PNEs). The Soviet Union detonated 122 PNEs from the mid-1960s through the late 1980s. The PNEs were conducted in a wide range of geologic settings and geographic locations, thus representing a unique data set for geophysical studies. These explosions were well recorded by the regional seismic networks, where thousands of seismograms are still retained. We are working to index these irreplaceable legacy analog seismograms and preserve them against loss for future generations. In the process, we are also generating high resolution scans of the seismograms and digitizing them for analysis. Most seismograms are from short period instruments, and when combined with the correct station calibration information, the digitization process accurately recovers ground motion signals to at least 5 Hz.

Promotional text: Thousands of seismograms from Peaceful Nuclear Explosions remain within the vaults of the regional seismic networks of the former Soviet Union. We are indexing, scanning, and accurately digitizing them to preserve these irreplaceable records for future geophysical research.

P2.5-712 – Reconstructing Nuclear Events from Annually Laminated Lake Sediments in Northern Finland

Authors: Ari-Pekka Leppanen[1]; Antti Kallio[1]; Eeva Haltia[2]; Timo Saarinen[2]
[1]*Radiation and Nuclear Safety Authority (STUK), Helsinki, Finland*
[2]*University of Turku, Finland*
Corresponding Author: ari.leppanen@stuk.fi

The annually laminated sediments deposited in Lake Kevojärvi (69°45N, 27°00'E) in the municipality of Utsjoki in Northern Finland were investigated for radioactivity. A freeze cores recovered from the 35-m deep basin preserve a distinct succession of annual laminations deposited between 1909 and 2015. The basic varve structure was composed of a detrital snowmelt layer and an organic-rich post-snowmelt layer lying on top of the snowmelt layer. A total of 53 annual laminations were taken for gamma spectroscopic measurements using low-background gamma spectroscopy. This allowed a reconstruction of ^{137}Cs, ^{241}Am and ^{210}Pb fallout history in the Lake Kevojärvi region. This highly resolved profile revealed a detailed record of anthropogenic radioactive fallout from atmospheric nuclear testing conducted in the 1950s and 1960s and the Chernobyl accident in 1986. The ^{137}Cs concentrations in sediment varves were first found to increase in 1956 while the peak years occurred in 1964, 1970 and 1986 varves. The ^{241}Am concentrations peaked in slightly different years in 1960-1962, 1964 and 1970 varves. Each peak was found to correspond to different nuclear testing campaigns. A two-year time delay between years of intensive nuclear weapons testing and peaks in the sediment records was observed due to sedimentation from the stratosphere.

Promotional text: Analysis of gamma-emitting radionuclides in annually laminated lake sediments are presented focusing on the anthropogenic ^{137}Cs and ^{241}Am which are also products of nuclear weapons testing.

6.3. Theme 3: Verification Technologies and Technique Application

This theme focuses on the systems used for the monitoring of nuclear explosions and the processing of the recorded data. It covers advances in traditional areas such as seismic, hydroacoustic, infrasound and radionuclide instrumentation, sensor networks, processing methodologies as well as the exploration of novel methods and the adaptation and integration of methods used in other fields. This includes how machine learning or artificial intelligence can assist in large data analysis, for instance to reduce analyst workload, enhance the quality of automatic products and improve event screening and discrimination in both waveform and radionuclide processing. Diverse sources of remotely sensed data may be useful in nuclear explosion monitoring. OSIs pose special challenges for sensors and associated equipment, which must be capable of detecting observables related to an event that triggered an OSI, especially those related to a nuclear test.

This theme provides an opportunity to review progress made on verification technologies in the 25 years since the Treaty opened for signature and to consider the possible technological advancements that could be attained in the next 25 years.

T3.1 Design of Sensor Systems and Advanced Sensor Technologies

Highlights

Seismic Sensors

The quality of the IMS seismic network might be improved by using rotation seismometry sensors. The absence of standardized metrological schemes for developers, manufacturers and users creates problems in data dissociation. P3.1-180 addressed metrological aspects in this developing field and presented a model for the estimation of measurement errors collected by rotational seismometers. P3.1-666 described the study by iXblue (France) using a fibre-optic gyroscope for measurements of rotational ground motion.

One of the main noise-causing factors in precise long period seismometry is temperature fluctuation of the mechanical elements of devices and sensitive sensors. To reduce such noise level, P3.1-393 suggested the use of precision, small sized temperature sensors. These precision sensors are capable of simultaneously monitoring the temperature at several points of a seismic device with an accuracy of at least 0.001 degrees.

P3.1-102 described a new system based on the moiré technique to calculate the displacement of the suspended mass in seismometers. An arrangement consisting of a laser diode, a narrow slit and a photodiode was also used to detect and record the signal from the displacement of the moiré fringes due to the oscillation of the suspended mass. The results show high performance and accuracy. P3.1-101 described a reliable damping system for this system that is based on eddy currents for the spring-suspended mass.

In P3.1-642, levels of background seismic noise were reported for IMS stations AS117 and AS118 in order to understand the behaviour of the IMS seismic stations in Venezuela. This study is useful for the analysis of background noise collected by these auxiliary sensors.

Radionuclide Technologies

P3.1-616 reported the acceptance tests of Xenon International, a next-generation radioxenon monitoring system developed at Pacific Northwest National Laboratory (PNNL) (USA) and manufactured by Teledyne Brown Engineering (TBE) (USA). The recently completed tests constitute phase 1 acceptance as a qualified system for the IMS. Xenon International processes samples every 6 hours, generating over 2.5 cc of xenon gas that is counted in a beta–gamma coincidence detector for 12 hours, resulting in unprecedented detection limits for radioxenon isotopes. Phase 1 testing was conducted at TBE and consisted of an acceptance visit by the PTS, radioxenon spikes processed on Xenon International and six months of uninterrupted automated sampling and analysis. Xenon International completed phase 1 testing with uptime greater than 98 per cent and routinely detected radioxenon isotopes that had never been detected at an IMS station, including ^{125}Xe, ^{127}Xe and ^{129m}Xe.

P3.1-434 presented the results of tests of the upgraded detection system of the MIKS complex prototype. The initial version of the beta–gamma coincidence detector of the MIKS system failed to meet the requirements on energy resolution of the beta channel and the memory effect. Now, the energy resolution of the beta channel of the redesigned detectors is 37–38 keV for the 129 keV line and the memory effect does not exceed 3 per cent, which meets PTS requirements. The All-Russia Research Institute of Automatics (VNIIA, Russian Federation) confirmed the readiness of the MIKS xenon isotope monitoring complex for IMS certification.

The Cinderella air sampler is currently used at approximately 7 per cent of the IMS radionuclide stations, with some systems operating for over 15 years. P3.1-299 described the PTS project preparing the integration of its replacement, the commercial automated particulate air sampling system Cinderella G2, into the IMS monitoring network.

P3.1-375 reported on the first tests of the world's first radioxenon array, which was installed in Sweden in 2020–2021. The array consists of five SAUNA CUBE units, placed 200–500 km apart. Each unit has a measurement sensitivity for 12 hours of samples. This is comparable to the SAUNA II systems presently used in the IMS, but at a fraction of the cost.

P3.1-216 described development of a silicon beta cell at PNNL (USA) for use as a potential modular replacement for the next-generation Xenon International system. Beta–gamma detectors are utilized extensively for the detection of radioxenon, where the beta detection is primarily performed with a plastic scintillator cell. Silicon is the leading candidate for future beta cell material due to its much improved energy resolution compared with plastic scintillators (factor of ~3x). The beta cell utilizes four different silicon detectors as opposed to the one channel plastic scintillators, which will necessitate data acquisition modifications.

P3.1-512 reviewed developments for noble gas detection at CEA/DAM (France). CEA/DAM developed the SPALAX system, which was first integrated into the IMS network in Tahiti in 2002. The current SPALAX system used by the IMS is under continuous improvement. In 2015, CEA/DAM started the conception and realization of the SPALAX New Generation (SPALAX-NG), integrating the results of several years of research and development on material adsorbents and electron/photon detectors. The first industrial SPALAX-NG system was released in 2017, and its qualification is currently being finalized by the PTS.

CEA/DAM continues to work on the metal exchanged zeolites (such as Ag/ZSM-5) relevant to xenon uptake and purification performance. O3.1-316 presented the results of the implementation of zeolite material in a pilot to capture xenon. In P3.1-670, the research centre SCK CEN (Belgium) presented work to assess materials for improved adsorption of xenon at IMS radionuclide stations under the EU Joint Action VII programme. The project was completed at the end of 2020.

In P3.1-669, Creare (USA) described its electrostatic precipitator collection system for the next generation of monitoring stations, RASA 2.0. This follows its design of a replacement for the current RASA system. Current work incorporates a full new design with several significant improvements including advanced detectors, increased particle collection efficiency, lower power consumption and potentially shorter collection times. The advanced two stage electrostatic precipitator system has shown greater than 90 per cent particle collection efficiency at both 0.2–0.3 μm and 10 μm particle sizes for 2000 m^3/hr flow rates using 1443 W.

P3.1-303 presented the first test implementation of a coincidence detector system for the measurement of particulate samples at the CTBTO Test Station located on the rooftop of the Vienna International Centre in Austria. The prototype is built upon previous coincidence systems developed at IMS radionuclide laboratory RL15 (AWE, UK). These systems have the potential to greatly improve the sensitivity of measurements and are being evaluated for deployment in the IMS.

Next-generation gamma–gamma coincidence measurements have the potential to significantly improve the confidence of detection of particulate radionuclides that are relevant for nuclear explosion monitoring purposes. Sophisticated laboratory systems have demonstrated order of magnitude improvements for radionuclides such as ^{106}Ru/^{106}Rh, ^{134}Cs and ^{144}Ce. However, the implementation of these systems at IMS particulate stations has been limited by the complexity of acquisition hardware, data processing and analysis techniques. P3.1-312 described development by PNNL and Mirion Technologies (USA) of a prototype system for that purpose. P3.1-187 reported results of gamma–gamma coincidence experiments where small amounts of ^{140}Ba (70 mBq or 150 mBq) were spiked onto high volume air filters (RASA and Cinderella). Gamma coincidence methods were able to detect the presence of ^{140}Ba after 24 hours of counting, whereas counting singles required several days for such detection.

A novel first-look cadmium zinc telluride detector was presented in P3.1-309. It is being developed by PNNL (USA) in collaboration with General Dynamics Mission Systems. The compact gamma spectrometer is designed to be installed within the air intake plenum of RASA analyzers at IMS radionuclide stations. It provides real time measurements (every 15 minutes) of the radionuclides collecting on the filters in advance of the standard measurements made 48 to 72 hours after sample collection. These measurements may provide an early indication of Treaty-relevant radionuclides for monitoring purposes.

P3.1-485 demonstrated the capability to produce gaseous radionuclides for quality assurance and calibration purposes at IMS radionuclide laboratories as well as for the calibration of equipment used for criticality monitoring. Gaseous fission products have been produced via neutron irradiation of a uranium target and extracted using a custom gas processing system for measurement on a high resolution beta–gamma coincidence detection system.

P3.1-506 presented an alpha–beta detector that can determine alpha and beta contamination based on pulse shape discrimination with digital pulse processing. It uses large surface detectors and rejects cosmic radiation background. The detector is designed for measuring contamination on large air sampling filters and to complement the high resolution spectrometry of gamma radiation. The detector is based on a ZnS scintillator. This system could be integrated in IMS radionuclide stations for an additional assay of the air filters.

Infrasound

P3.1-221 discussed PTS activity to monitor developments in the field of low cost infrasound sensors. In recent years, an increasing number of such low cost sensors have been developed, such as the Raspberry Shake and Boom, the iTem Prs0025a and the Gem Infrasound Logger v1.01. The PTS aims to stay on the pulse of infrasound sensor development and to spot new opportunities for the future of the monitoring system.

P3.1-128 evaluated Hyperion 5313A infrasound sensors to determine the time it takes the sensors to thermally equilibrate under a variety of environmental conditions. This work will help determine suitable procedures for station operators when installing these sensors.

Adding more sensors to infrasound arrays increases their resolving power, facilitating the detection of weak signals and the identification of multiple simultaneous waves from different directions. Complex infrasound wavefields (containing multiple simultaneous waves with different slowness vectors) pose a challenge for traditional array analysis. P3.1-665 approached this problem using a dense array (22 sensors) as a field method, and secondary infrasound from earthquakes as a research target. Using both direct waves from a local earthquake and refracted waves from a regional event, it was shown that the detail and resolving power provided by array analyses can be improved dramatically by increasing the number of sensors in the array.

P3.1-520 presented a wind noise reduction system developed by Enviroearth (France) that uses advanced technologies that meet all the requirements and topology constraints of the infrasound stations in the IMS network.

O3.1-579 focused on the testing of an innovative system for calibrating infrasound sensors developed by CEA-DAM (France). The first tests were conducted in 2019–2020 as part of the installation and certification of IMS infrasound station IS25 (Guadeloupe). A total of 20 microbarometers were qualified on-site. The method will be presented to the metrology community within the framework of the European Infra-AUV project in 2022.

P3.1-115 highlighted the performance of a major upgrade of infrasound array IS31 (Kazakhstan) using up to date equipment and techniques to enable its continuous and improved operation. The station is situated in a remote location with harsh climate conditions. Over its 20 year period of operation, experience has been gained in operating the array in strong winds, low winter temperatures and springtime flooding. All critical systems were renovated, and calibration capability was added. The possibility of remote array control is of prime importance for areas that are difficult to access.

P3.1-618 described the expansion of the infrasound network in Ukraine by using inexpensive digital condenser microbarographs. The instrument has a frequency range of 0.05–15 Hz, a sensitivity of 40 mV/Pa, and an amplitude range of 200 Pa. Several arrays have been installed, and tests of these microbarographs on the elements of seismic station PS45 (Ukraine) have also been successfully carried out. The installation of seven microbarographs is planned. For research purposes, a three-element mobile array is available.

P3.1-713 discussed the engineering development and evaluation of a coherent (non-explosive, periodic, with controlled duration) infrasound source. Prototype testing has verified the capability of generating continuous signals at a fundamental frequency of 0.25 Hz at ranges greater than 1 km in low wind conditions. Generation of harmonics of this fundamental frequency throughout the 0.25–4.0 Hz band with reasonable signal to noise ratio was also demonstrated.

Hydroacoustic Technologies

O3.1-384 discussed the potential for integration of distributed optical fiber sensors into IMS hydroacoustic systems. Over the last decade, methods have been developed that use existing telecommunications cables to measure seismic, acoustic and temperature signals with surprising sensitivity, to sub-meter spatial resolution in some cases and with cable runs greater than 100 km in others. P3.1-293 compared observations performed by distributed acoustic sensing (DAS)

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

using a fibre-optic submarine cable with data from co-located hydrophones. Broadband frequency signals associated with air gun shots were recorded. DAS measured the Rayleigh backscattering variations along a fibre-optic cable of the same kind as the trunk cables used for IMS hydrophone stations. DAS agreed with recordings from co-located hydrophones. Since DAS is performed along a fibre-optic cable of several tens of kilometres length, it can be used for array observations.

O3.1-467 presented an external calibrator system developed by the National Center for Physical Acoustics (USA) that is nearing maturity. This calibrator is attached as a replacement sensor lid for the Hyperion sensor and injects the signal into the back volume of the sensor. The integrated sensor–external calibrator package behaves as a self-calibrating sensor that can operate nominally and without significant change in response. The system is capable of producing signals with amplitudes greater than 20 Pa in the operational environment between 0.01 Hz and 10 Hz.

P3.1-396 reported on the development and tests of a new prototype of a geo-hydroacoustic buoy at the Schmidt Institute of Physics of the Earth (Russian Federation) that is designed to collect acoustic, hydroacoustic or seismoacoustic data in various environmental conditions. The main purpose of the buoy development was for operational use in the Arctic latitudes as an element of distributed drifting ice-class antennas. The buoy can be installed in onshore and offshore wells and is suitable for use at IMS stations in polar conditions.

On-Site Inspection

O3.1-190 discussed the development of compact, high performance hardware for digital data evaluation methods that is especially useful in handheld devices used for OSIs due to their lower weight, power supply and cost. As an example, test results regarding the influence of firm- and hardware on the performance of a wearable radiation isotope identifier device (RIID) was presented.

O3.1-296 highlighted a study on the potential of using time-lapse seismic surveying to identify ground zero by monitoring post-explosion dynamic phenomena. Time-lapse seismic surveying is successfully employed in the oil and gas industry. The suggested technique is envisaged for field deployment during OSI to locate the zone of four dimensional change or source location.

P3.1-495 proposed the use of a wide spectral imaging spectrometer mounted on aviation platforms (including unmanned aerial vehicles). Several application fields using hyperspectral data were analysed. The spectrometer has a wide spectrum range from VIS to MWIR (0.4μm–5μm) with high signal to noise ratio (1000).

Positioning and navigation are essential for inspectors in the inspection area and very important for most OSI measurements. With the development of global navigation satellite systems (GNSSs), including GPS, GLONASS, GALILEO and BEIDOU, P3.1-302 proposed a four mode GNSS solution for OSI that is compatible with all existing satellite navigation systems and more reliable. This system could be easily connected with the Integrated Information Management System for OSI.

P3.1-527 presented the results of extensive tests as part of the development of a portable backpack system for the measurement and identification of radioactive material and, at the same time, determination in real time and without the support of experts, the presence of special nuclear material (SNM) isotopes. The performance exceeds the reference standards in sensitivity and in SNM identification. The device is based on an organic liquid scintillator with pulse shape discrimination for the simultaneous detection of gamma rays and neutrons.

Combining Technologies

P3.1-265 focused on a tabletop exercise by the Austrian NDC in November 2020 in which scheduled ground detonations were monitored. In addition to the nearby permanent seismic station ABNA, the NDC deployed two seismic broadband stations with co-located low cost seismic and infrasound sensors as well as a mobile infrasound array to evaluate the quality of the different seismic sensors as well as the added value of the low cost infrasound sensor.

General

P3.1-243 presented CalxPy, a web application developed at the PTS for the calibration of geophysical systems. CalxPy is a versatile software solution that supports the implementation of a passive and traceable calibration method based on the principle of comparison against a reference. This method can be applied across all IMS waveform technologies.

P3.1-524 described a compact timing board developed by CEA/DAM (France) in partnership with the start-up Fullscale. The board is easily integrated with any equipment with accurate dating needs and based on global navigation satellite system reception to get an absolute time reference anywhere in the world. Its extra small size and very low consumption (<40 mW) allow it to be embedded in any kind of device, such as compact digitizers or digital sensors. This module meets the PTS requirements in terms of timing and will soon be integrated in SMAD and MB3d digitizers.

P3.1-203 suggested a practical automatic weather station solution to IMS/OSI support that provides meteorology data, such as temperature, wind speed, wind direction, humidity, air pressure and rainfall, to support IMS station maintenance, OSI sampling and overflight, as well as the health and safety of the inspection team.

P3.1-256 described a low cost weather station that was designed and developed in Nepal for the measurement of temperature, relative humidity, air pressure, wind direction, wind speed, light intensity and precipitation. The device was set up according to the guidelines of the World Meteorological Organization and generated data that was compared with standard meteorological station for data validation.

P3.1-104 focused on the development by VNIIA (Russian Federation) of short-period vertical and three component broadband seismic receivers and a microbarometer for infrasound monitoring systems. Preparations for certification of the noble gas monitoring equipment MIKS, a xenon isotope monitoring system, were also presented.

O3.1 Design of Sensor Systems and Advanced Sensor Technologies Abstracts of Oral Presentations

O3.1-190 – Radiation Detection for OSI: The Influence of Firmware on Detector Performance

Author: Monika Risse[1]
Co-authors: Marie Charlotte Bornhoeft[1]; Jeannette Glabian[1]; Theo Koeble[1]; Hermann Friedrich[1]
[1]*Fraunhofer Institute for Technological Trend Analysis INT, Euskirchen, Germany*
Corresponding Author: monika.risse@int.fraunhofer.de

Radiation detection devices comprise a detection unit and a signal evaluation unit, each adapted for the specific application of the device. Traditionally, signals of radiation detectors were evaluated utilising analogue methods, such as the standardised NIM electronics. Developments towards compact, high-performance digital hardware resulted nowadays in the application of digital data evaluation methods, both especially useful in hand-held devices used for on-site inspections due to lower weight, lower power supply and lower costs. The rise of

digital data evaluation methods led to a variety of approaches and implementations, as no standardisation for digital data evaluation has been commonly agreed on so far. Therefore, it is essential to be aware of the influence of the implemented firmware on the detector performance. Exemplarily, we will present our test results regarding the influence of firm- and hardware on the performance of the D3S, a wearable Radiation Isotope Identifier Device (RIID) from Kromek. The results have been gained utilising our QuTeSt (Qualification Test System for Radiation Detection Devices), a test environment to perform dynamic and static test measurements in accordance with international standards e.g. ANSI, IEC or ITRAP+10. Powerful hand-held radiation detection devices with approved quality are of utmost importance for good OSI performance.
Promotional text: The success of on-site inspections relies heavily on the performance of sensor systems. The presented study will demonstrate the importance of valid firmware for reliable detector performance.

O3.1-296 – Detecting Underground Nuclear Explosion-Related Dynamic Phenomena Using Time Lapse Seismic Surveying

Author: Shaji Mathew[1]
Co-authors: Colin MacBeth[1]; Jenny Stevanovic[2]; Maria-Daphne Mangriotis[3]
[1]*Heriot-Watt University, Aberdeen, United Kingdom*
[2]*AWE Aldermaston, Reading, United Kingdom*
[3]*University of Edinburgh, United Kingdom*
Corresponding Author: sm280@hw.ac.uk

Underground nuclear explosions produce an immense change in pressure and temperature concentrated around the source origin. This results in the formation of characteristic static and dynamic phenomena. This study highlights the potential of using time-lapse seismic to identify ground zero by monitoring post-explosion dynamic phenomena. Time-lapse seismic is successfully employed in the oil and gas industry. It involves taking more than one 2D/3D survey at different calendar times over the same reservoir and studying the difference in seismic attributes. Dynamic changes in rock and fluid properties due to UNE are observable for a prolonged period, even up to several decades. This is prominent near to source origin and is a result of the redistribution of residual energy, such as pressure, temperature, and saturation. Frequent seismic monitoring surveys (time-lapse seismic) would enable monitoring of changes to rock and fluid properties. The characteristics of the time-lapse seismic signature in a heterogeneous medium (or heterogeneous cavity), and the factors affecting land 4D repeatability on the 4D signature are discussed. We present a fast detection method using machine learning for the detection of explosion-related time-lapse signatures, which could be used to identify the source location or ground zero.
Promotional text: This study highlights the potential of using time-lapse seismic to identify ground zero by monitoring post-explosion dynamic phenomena. The suggested technique is envisaged for field deployment during on-site inspection to locate the zone of 4D change or source location.

O3.1-316 – Update on Xenon Adsorbent Development at CEA/DAM

Author: Gabriel Couchaux[1]
Co-authors: Sylvain Topin[1]; Antoine Cagniant[1]; Arnaud Monpezat[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: gabriel.couchaux@cea.fr

In the context of the Comprehensive Nuclear Test Ban Treaty (CTBT), CEA/DAM developed about 20 years ago the SPALAX (Système de Prélèvement Automatique en Ligne avec l'Analyse du Xénon) system, which is used in the International Monitoring System to detect xenon releases following a nuclear explosion. This system is still under continuous improvement. In particular, CEA/DAM continues to work on the metal exchanged zeolites

(such as Ag@ZSM-5) which are very relevant with regard to the Xe uptake and purification performances. CEA/DAM developed recently a new research pilot to extend its capabilities to test such materials. This presentation aims at providing an update on CEA/DAM material developments.
Promotional text: This study aims to present the results of the implementation of zeolite material in a pilot to capture xenon.

O3.1-384 – Distributed Optical Fiber Sensing and Its Potential Application for IMS Hydroacoustic Stations

Authors: Geoffrey Cram[1]; Dale Winebrenner[1]; William Wilcock[1]; Kevin Williams[1]
[1]*University of Washington, Seattle, WA, USA*
Corresponding Author: cramg@uw.edu

Distributed optical fiber sensors (DOFSs) utilize specialized source and detection systems to convert optical fibers into linear arrays of sensors. Since early experiments in the 1980s, a range of methodologies has been developed to sense a diverse set of variables with varying sensitivities and precisions based on communication-grade as well as purpose-built optical fiber cables. Over the last decade, methods have been developed that use existing telecommunications cables to measure seismic, acoustic and temperature signals with surprising sensitivity, to sub-meter spatial resolution in some cases and with cable runs greater than 100 km in others. We review three principal techniques used to derive these measurements, together with their strengths and weaknesses, performance trade-offs, and system and environmental implementation constraints. We provide examples of existing and planned subsea implementations, and discuss the potential application of such technologies for integration into IMS hydroacoustic system sensor packages or as additional science sensors.
Promotional text: The fundamentals and applications of distributed optical fiber sensors (DOFSs) are reviewed in light of their potential for integration into IMS hydroacoustic systems.

O3.1-467 – An External Calibrator System for the Hyperion Sensors

Author: Carrick Talmadge[1]
[1]*National Center for Physical Acoustics, University of Mississippi, MS, USA*
Corresponding Author: clt@olemiss.edu

The NCPA has developed an external calibrator system which is nearing maturity. This calibrator is attached as a replacement sensor lid for the Hyperion sensor, and injects the signal into the back volume of the Hyperion sensor. When the external calibrator is mated to the sensor, the integrated sensor-external calibrator package behaves as a self-calibrating sensor. The external calibrator allows the Hyperion to operate nominally and without significant change in response with the external calibrator installed. The calibrator is driven by an external signal generated by the digitizer (e.g., the CAL signal on a GEOTECH). This system is capable of producing signals with amplitudes greater than 20-Pa in the operational environment between 0.01-10 Hz. We report here on the performance metrics (frequency flatness, level linearity, etc.) as well as summarize the theory of operation of the device.
Promotional text: We will discuss the development of an external calibrator technology which can be used with the Hyperion sensors, which allows them to behave as self-calibrating sensors.

O3.1-579 – Innovative On-Site Infrasound Metrology Conducted in 2019 and 2020

Author: Paul Vincent[1]
Co-authors: Anne-Sophie Morlens[1]; Guillaume Rouille[1]; Franck Larsonnier[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: paul.vincent@cea.fr

In order to improve the confidence in the results of measurements carried out in the field, on-site metrology is a key step. With the medium-term objective of being able to deploy a portable metrology system on different infrasound stations, CEA-DAM has tested an innovative system for calibrating its infrasound sensors. The first tests were conducted in November 2019 and September 2020 as part of the installation and certification of the IMS IS25 infrasound station in Guadeloupe. A total of 20 microbarometers were qualified on site. We present the equipments deployed, the methods used and the results of the measurements carried out. It appears that the preliminary results show a very good correspondence between the measurements performed in the field, under particular environmental conditions, and the measurements performed in the metrology laboratory. The method will be confronted to the metrology community within the framework of the European Infra-AUV project in 2022.
Promotional text: In order to improve the confidence in the results of measurements carried out in the field, on-site metrology is a key step. CEA-DAM has tested an innovative system for calibrating its infrasound sensors.

P3.1 Design of Sensor Systems and Advanced Sensor Technologies Abstracts of Poster Presentations

P3.1-101 – A New Damping System for Seismic Sensors Based on Eddy Currents

Author: Shamseddin Esmaeili[1]
[1]*Razi University of Kermanshah, Kermanshah, Iran*
Corresponding Author: s.esmaeili@razi.ac.ir

This research describes a new damping system for optical seismic sensors that, is based on eddy currents. In the last decade, scientists have been considered optical approaches for readout systems of seismic sensors. So, the use of reliable and high-performance damping systems in this category of seismometers is very important. This has led us to build a damping system based on the eddy currents for a spring-suspended mass whose position is monitored by the moiré technique. To demonstrate this approach, a conventional oscillation system has been used. Also, the proposed damping system consists of a neodymium magnet which is fixed to the suspended mass, and a conductive plate which is fixed to the frame of the oscillator. The magnet and the conductive plate are facing each other with a distance of 0.5 mm. By relative motion between the magnet and the nearby conductive plate, eddy currents have been produced in a way that opposes its creator. Experiments to test this approach have been performed, and the evaluations of the results show that the proposed damping system for optical sensors is quite reliable.
Promotional text: The present study describes a new approach to building a reliable damping system for optical seismic sensors, that is based on eddy currents. The evaluations of the results show that the proposed damping system is quite practical and efficient.

P3.1-102 – An Approach for Determination of Suspended Mass Displacements in Seismometry

Author: Shamseddin Esmaeili[1]
Co-author: Anooshiravan Ansari[2]
[1]*Razi University of Kermanshah, Kermanshah, Iran*
[2]*International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran*
Corresponding Authors: a.ansari@iiees.ac.ir, s.esmaeili@razi.ac.ir

In this research, a new approach based on the moiré technique is presented to calculate the displacement of the suspended mass in seismometers. The oscillating system consists of a spring-suspended mass whose position is monitored using the moiré technique. To form the moiré pattern, two similar Ronchi grating are used so that they are facing each other without physical contact. One of the gratings is fixed to the oscillating mass and the other to the body of the oscillating system. An arrangement consisting of a laser diode, a narrow slit, and a photodiode was also used to detect and record the signal from the displacement of the moiré fringes due to the oscillation of the suspended mass. Also, an algorithm for calculations and conversion of the electrical signal into the displacement signal is presented. To validate the equations and the proposed algorithm, simulated and real data were evaluated and the results were compared. The results show the high capability and accuracy of the moiré technique and proposed algorithm in determining the oscillating mass displacement.
Promotional text: This research demonstrates a novel method to calculate the displacement of the suspended mass in seismometers that is very important in seismometry. This method is based on the moiré technique and an algorithm to process the recorded signals.

P3.1-104 – FSUE VNIIA Contribution to the Development of CTBT-Related Technologies

Author: Oleg Gerasimchuk[1]
Co-author: Gleb Zasimov[1]
[1]*All-Russia Research Institute of Automatics named after N. L. Dukhov (VNIIA), Moscow, Russian Federation*
Corresponding Author: glebzasimov@yandex.ru

VNIIA is the premier ROSATOM organization in implementing the CTBT and is currently performing a cluster of research activities:
- provides scientific methodological support and develops hardware and software solutions to ensure the CTBT OSI activities, carries out a comprehensive assessment and foresee of technical abilities within the verification regime for compliance with the CTBT, analyzes the effectiveness of control means and the level of information of IDC data;
- participates in the analysis of events, indicating possible non-compliance with the Treaty by States Parties; gathers geophysical and radionuclide data based on IDC products;
- improves the information and analytical system in order to use it in the applied research for the activities of Rosatom within the CTBT verification regime;
- explores and refines capacities of complex-analytic techniques usage in determination the nature of the suspicious event with IMS data;
- develops and implements modernization of the E-Training System Software for training of surrogate inspectors in OSI methods and procedures;
- develops short-period vertical and three-component broadband seismic receivers for seismic monitoring systems;
- develops a microbarometer for infrasound monitoring systems;
- VNIIA specialists proceed with the preparations for certification of NG monitoring equipment of domestic development–Xenon Isotopes Monitoring System (MIKS).
Promotional text: VNIIA is the leading organization of the

“Rosatom” regard to the CTBT regime. VNIIA strives to develop scientific research and international cooperation that can serve national needs, achieve political objectives in support of the CTBT.

P3.1-115 – Major Upgrade of the I31KZ: Learning the Lessons of the Past and Keeping Up with the State of the Art

Authors: Alexandr Smirnov[1]; Andrey Anuchin[1]; Sergelen Bazarragchaa[2]; Nikolai Burbyga[1]; Pavel Martysevich[2]
[1]*Institute of Geophysical Research, Almaty, Kazakhstan*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: infra.smirnoff@gmail.com

I31KZ, Kazakhstan, has been in operation for almost twenty (20) years. Over this period, the specific experience was gained of operating the array in hard-to-reach areas in harsh environmental conditions such as strong winds, low temperature in winter months and flooding in springtime. This experience and lessons learned allowed to minimize the risks of potential damage and loss of detectability. All critical systems, which became obsolete over the long operating period, were renovated and the most advanced available technical solutions were implemented. The station was brought to the state-of-the-art for infrasound installations. Calibration capability was added, namely site-by-site and electrical calibration of MB3a via digitizer, which became a breakthrough in station operation control. The possibility of remote array control is of prime importance for hard-to-access areas. This additional element and commonality of wind noise suppression systems improve station robustness and increases array performance, which is critical for the area with high wind noise levels. Upgrade of the power system and application of several up-to-date solutions, such as Low-noise power supplies and switch to Ethernet fiber optic from serial radios resulted in significantly higher accessibility and data quality, as evidenced by the attached statistical graphs and PSD plots.

Promotional text: A major upgrade of the I31KZ infrasound array considering the experience of array operation in a remote location and under harsh climate conditions using up-to-date equipment and techniques improved the station’s ability for nuclear test monitoring and verification.

P3.1-128 – Thermal Equilibration of Hyperion Infrasound Sensors

Author: Bion John Merchant[1]
Co-author: Randy Rembold[1]
[1]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
Corresponding Author: bjmerch@sandia.gov

An evaluation of several Hyperion 5313A infrasound sensors was performed in order to determine the length of time it takes for the sensors to thermally equilibrate under a variety of environmental conditions. The motivation for performing these tests was to aid in determining suitable procedures for station operators to follow when installing these sensors. Thermal equilibration occurs when the temperature of the component materials of a sensor are equalizing with its environment. This can occur when the sensor is exposed to an environment with a different ambient temperature or when the sensor is first powered on, both of which typically occur during the installation of a sensor. During the equilibration period, the measured noise on the sensor output can be considerably higher than when it has thermally stabilized.

P3.1-180 – Metrology of Rotational Seismometry

Authors: Konstantin Kislov[1]; Valentin Gravirov[2]
[1]*Institute of Earthquake Prediction Theory and Mathematical Geophysics (IEPT RAS), Moscow, Russian Federation*
[2]*The Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences (IPE RAS), Moscow, Russian Federation*
Corresponding Author: kvkislov@yandex.ru

Rotational seismometry is an emerging perspective area of science for further developing of seismic monitoring. The quality of manufacturing measuring devices is improving. New instruments are being developed. Accuracy of measurements is increasing. Data processing algorithms are being improved. However, the absence of standardized metrological schemes for developers, manufacturers and users creates problems in data dissociation. The data can't be compared. Metrological characteristics of devices should be standardized. All the necessary characteristics must be clearly defined for each type of device. Then we can trust and analyze all monitoring data. This paper presents the model of the estimation of errors of measurements collected by the rotational seismometer.

Promotional text: The quality of the IMS seismic network of the CTBT can be improved by using rotation sensors. There is still a lot of work to be done in this field. The paper presents overview of the metrological problems in rotational seismometry, which require further improvement.

P3.1-187 – Low-Level ^{140}Ba Measurements on High-Volume Air Filters Using Gamma Coincidence Systems

Authors: Judah Friese[1]; Jonathan Burnett[1]; Brandy Gartman[1]; Ashley Davies[2]; Matthew Goodwin[2]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
[2]*AWE Aldermaston, Reading, UK*
Corresponding Author: judah.friese@pnnl.gov

It has been proposed that the use of gamma-gamma coincidence methods could lower the detection limit for the detection of certain relevant radionuclides, such as ^{140}Ba. Gamma coincidence measurements have the advantage of significantly lowering the background at the cost of lower overall efficiency. Modelling efforts indicate that a net gain in detection limit can be achieved. Several experiments were designed where small amounts of ^{140}Ba was spiked at 70 mBq and 150 mBq onto high-volume air filters (RASA and Cinderella). These filters were measured on several gamma singles and coincidence systems, both on the surface and in shallow underground laboratories. Initial results show a benefit of coincidence systems over gamma singles when measured in the typical IMS process (24 hours collect, 24 hours decay, 24 hours count). Gamma coincidence methods were able to detect the presence of ^{140}Ba after 24 hours of counting, whereas singles required several days of counting to detect ^{140}Ba. Accurate ^{140}Ba/^{140}La separation time was also able to be accurately calculated using coincidence methods.

Promotional text: Utilizing advanced gamma spectroscopy methods such as gamma coincidence measurements can increase the sensitivity of the IMS for relevant radionuclides that have decay schemes that emit coincidence gamma rays.

P3.1-203 – Commercial Automatic Weather Station Solution to IMS/OSI

Author: Peng Li[1]
Co-authors: Jianhui Xi[2]; Jian Wu[2]; Xinmin He[1]; Lingxue Wei[1]; Yuan He[1]
[1]*Hope Investment Development Corp. Ltd., Beijing, China*
[2]*SANTEL Technology & Trading Corp., Beijing, China*
Corresponding Author: lipeng1406@163.com

Weather forecast is essential for precision measurements involving meteorology related CTBT scenarios. Weather parameters recording is also very critical for routine maintenance of IMS stations. Looking at the IMS network all over the globe, it would be very important to get to know the local weather situation to support the normal operation of the four categories of IMS stations in the middle of nowhere. For OSI operations, mission critical sampling operation, especially radioactive noble gas sampling, relies heavily on the accurate forecasting of wind directions with time. Even the proper selection of base of operations out of the concerns of health and safety, also relies on the proper study of weather conditions of the inspection area. This work would propose a commercial automatic weather station solution, which is not only quite suitable for CTBT OSI mission requirements, but also for IMS station operation support. This automatic weather station is self-sufficient with solar-panel power supply. It also has a built-in compact design, which could provide all basic parameters of meteorology, such as temperature, humidity, wind direction and speed, air pressure, rain gauge, et cetera. The system could be connected through wire or wireless communication to other CTBT equipment through RS232/GPRS/4G.

Promotional text: This work would provide a practical automatic weather station solution to IMS/OSI support, which provides meteorology data, such as temperature, wind speed, wind direction, humidity, air pressure, rainfall to support IMS station maintenance, OSI sampling, overflight, and IT H&S.

P3.1-216 – Development of a Radioxenon Detector with a High Resolution Beta Detector

Authors: Michael Foxe[1]; Michael Mayer[1]; Johnathan Slack[1]; Eric Becker[1]; Alex Couture[1]; Thomas Hallen[1]; Mike Ripplinger[1]; James Hayes[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: michael.foxe@pnnl.gov

Beta-gamma detectors are utilized extensively for the detection of radioxenon, but the beta detection is primarily performed with a plastic scintillator cell. Two areas of improvement for plastic scintillators are the sample carry-over ("memory effect") and energy resolution. While the scintillator can be coated to remove the memory effect, the energy resolution must be improved with a different detector material. Silicon is the current leading candidate for the future beta cell material due to the much-improved energy resolution compared to plastic scintillators (factor of ~3x). PNNL is developing a silicon beta cell for use as a potential modular replacement within Xenon International (a next-generation radioxenon detection system currently undergoing acceptance testing for potential inclusion in the International Monitoring System). The beta cell utilizes four different silicon detectors to create an active volume for the radioxenon within an outer gas cell. Since there are four separate beta signals (compared to one for plastic scintillators), data acquisition modifications are required. In this presentation, we detail the design, efficiency measurements, and long-term testing of the silicon beta cell and potential improvements in isotopic discrimination. Additionally, we discuss the required data acquisition and analysis updates needed to best utilize the silicon improvements.

Promotional text: Improving identification of nuclear explosions in a sea of anthropogenic backgrounds with the improved isotopic discrimination available with a silicon beta cell.

P3.1-221 – Current PTS Activities Related to Low-Cost Infrasound Sensors

Author: Alfred Kramer[1]
Co-authors: Julien Marty[1]; Benoit Doury[1]; Moctar Moumouni Kountche[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: alfred.kramer@ctbto.org

Infrasound sensors deployed in the IMS Infrasound Network are of high performance so they can meet the strict IMS minimum requirements. The PTS in its effort to deploy state-of-the-art infrasound sensors has been performing continuous technology watch for the last 11 years on high quality infrasound sensors. More recently, the PTS also started monitoring developments in the field of low-cost infrasound sensors. The objective is to stay on the pulse of infrasound sensors development and also to spot new infrasound sensing technologies, with great potential for the future, at an early stage. In recent years an increasing number of low-cost infrasound sensors have been developed. The PTS has made a concerted attempt to explore and test those low-cost infrasound sensors. Sensors such as the Raspberry Shake and Boom, the iTem Prs0025a and the Gem Infrasound Logger v1.01 has been tested. This poster present the testing observations made of those types of sensors.

Promotional text: More recently, the PTS also started monitoring developments in the field of low-cost infrasound sensors. The objective is to stay on the pulse of infrasound sensors development and also to spot new infrasound sensing technologies, with great potential for the future.

P3.1-243 – CalxPy: Software for the Calibration of Geophysical Systems Against a Reference

Authors: Benoit Doury[1]; Ichrak Ketata[2]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Zuehlke Engineering, Vienna, Austria*
Corresponding Author: benoit.doury@ctbto.org

The IMS Operational Manuals for waveform stations require that IMS stations be calibrated regularly. Since 2012, the PTS had relied mostly on electrical calibration to meet that requirement. However electrical calibration comes with some challenges (no traceability, integration and sustainment issues, high operating costs...). A part of the geophysical community, including Station Operators, has started performing regular calibrations by comparison against a co-located reference. This method allows a more systematic and centralized approach to calibration. Over the past few years it has been gradually more used at IMS stations, particularly infrasound. In this context, the PTS is developing tools to support this alternative approach. Here we present CalxPy, a web-application developed at the PTS for the calibration of geophysical systems by comparison. With CalxPy, one can calculate, store and display the response of a system for a given period, or track the evolution of the response against time or environmental variables. CalxPy also allows the refinement and evaluation of the measured response against a baseline, and the reporting of IMS2.0 calibration results. CalxPy supports the Initial calibration and On-site yearly calibration processes, as well as Data Quality Control. CalxPy can be deployed in the IDC pipeline and in NDC-in-a-box.

Promotional text: CalxPy is a versatile software solution that supports the implementation of a passive and traceable calibration method based on the principle of comparison against a reference. This method can be applied across all IMS waveform technologies.

P3.1-256 – Technology for Disaster Resilience: Low-Cost Weather Station

Authors: Hemu Kafle[1]; Shrayarrn Khatiwada[1]
[1]*Kathmandu Institute of Applied Sciences (KIAS), Nepal*
Corresponding Author: hemukafle@gmail.com

Despite the prudent importance of monitoring weather and climatic trends, the cost of setting up weather monitoring experiments and devices prove to be costly and even with available costly solutions, they are without standardization rendering the data collected from them unusable for scientific enquiries or examinations. The objective of the work described in this paper is detail the activities done to create mass producible weather monitoring station with low starting and maintenance cost that is capable of generating scientifically usable data of good precision and accuracy and equip weather scientist, world over, with such technology to fight against hydro-meteorological disasters. To achieve these objectives a prototype of embedded micro processor system was developed and iteratively improving it at field tests for thermal capabilities, power consumption, data delivery systems and processing modes. The improved device was setup according to the guidelines of World Meteorological Organization and then generated data was compared to standard meteorological station for data validation. The data fit was performed by time-stamp comparison and functional compensation of the biases and non-linearity. The developed prototype was designed in to a Printed Circuit Board for commercial production into consumer off the shelf form factor.

Promotional text: Low cost weather station is design and developed in Nepal for the measurement of temperature, realtive humidity, air pressure, wind direction, wind speed, light intensity and precipitation. These parameters are very essential for observing any types of disaster on earth.

P3.1-265 – Added Value of Low-Cost Seismic and Infrasound Sensors to Local Monitoring

Authors: Maria-Theresia Apoloner[1]; Ulrike Mitterbauer[1]; Peter Mohr[2]; Fee-Alexandra Rodler[1]
[1]*Central Institution for Meteorology and Geodynamics (ZAMG), Vienna, Austria*
[2]*Ministry of Defence, Vienna, Austria*
Corresponding Author: mt.apoloner@gmail.com

In the framework of a tabletop-exercise of the Austrian NDC scheduled ground detonations within a week in November 2020 were monitored. Therefore, a local network was deployed. Additional to the permanent seismic station ABNA in the vicinity, the NDC deployed two seismic broadband stations with co-located low-cost seismic and infrasound sensors as well as a mobile infrasound array. After the location of the scheduled ground explosions further analysis of the waveform data was performed: we reviewed the quality of the different seismic sensors as well as the added value of the low-cost infrasound sensor. Additionally, we looked into the background noise at the newest permanent station ABNA of the Austrian Seismic network.

Promotional text: In the framework of a tabletop-exercise of the Austrian NDC scheduled ground detonations within a week in November 2020 were monitored. Therefore, a local network was deployed. Additional to the permanent seismic station ABNA in the vicinity, the NDC deployed two seismic broadband stations with co-located lowcost seismic and infrasound sensors as well as a mobile infrasound array.

P3.1-293 – Hydroacoustic Observations Using Distributed Acoustic Sensing Technology on a Fibre-Optic Submarine Cable

Authors: Hiroyuki Matsumoto[1]; Eiichiro Araki[1]; Toshinori Kimura[1]; Kazuya Shiraishi[1]; Takashi Tonegawa[1]; Gou Fujie[1]; Koichiro Obana[1]; Ryuta Arai[1]; Yuka Kaiho[1]; Yasuyuki Nakamura[1]; Takashi Yokobiki[1]; Shuichi Kodaira[1]; Narumi Takahashi[2]; Robert Ellwood[3]; Victor Yartsev[3]; Martin Karrenbach[3]
[1]*Japan Agency for Marine-Earth Science and Technology, (JAMSTEC) Yokosuka, Kanagawa, Japan*
[2] *National Research Institute for Earth Science and Disaster Resilience (NIED)*
[3] *OptaSense, Inc.*
Corresponding Author: hmatsumoto@jamstec.go.jp

A ship-based air-gun survey was conducted contemporarily with distributed acoustic sensing (DAS) observations using an abandoned submarine cable. Measurements were compared between DAS and co-located hydrophones on the seafloor. DAS measures the Rayleigh back-scattering variations along a fiber-optic cable, of the same kind as the IMS HA hydrophone stations' trunk cables, using incident laser light from the cable terminal. From this measurement, strain or strain rate are obtained. It is known that both spatially- and temporally-dense measurements are achieved with DAS technology, and therefore 50-km length DAS was performed with 10-m resolution and 500-samples per second (SPS). The submarine cable was on the seafloor, except for a 2-km buried section, and reaching 1000 m depth. Broadband frequency signals associated with the air-gun shots recorded by DAS agreed with recordings from co-located hydrophones. The amplitude of DAS strain rate is correlated to pressure at a frequency range above 2 Hz. We also investigated the capability of DAS to measure ocean microseismics (peak frequency ~0.1 Hz), which were identified along the entire submarine cable up to 50 km. Since DAS is performed along a fiber-optic cable of several tens of kilometers length, it can be used also for array observations.

Promotional text: Hydroacoustic observations of air-gun shots by distributed acoustic sensing (DAS) using a fiber-optic submarine cable, and comparison with data from co-located hydrophones, show that DAS can detect hydroacoustic signals. Our data suggests DAS can be used for array observations.

P3.1-299 – Maintaining IMS Particulate Radioactivity Measurement Capabilities: Integration of a Next-Generation Automated Air Sampler, Cinderella G2

Authors: Aleksandr Tarasov[1]; Richard Britton[1]; Nikolaus Helmut Hermanspahn[1]; Bernd Wernsperger[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Authors: nikolaus.hermanspahn@ctbto.org, richard.britton@ctbto.org, bernd.wernsperger@ctbto.org, aleksandr.tarasov@ctbto.org

The international monitoring network of radionuclide stations of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) has been built up for the last 20 years. This mature monitoring network has now reached a phase where a technology upgrade for some systems has become necessary. The Cinderella G2 is a commercial automated particulate air sampling system, due to replace the first generation Cinderella air sampler. This sampler is currently used at ~7% of radionuclide IMS stations, with some operating for over 15 years. Deployment of the second generation systems requires an integration of the commercial system into the IMS hardware and software environment. This PTS project aims to achieve this integration, simplifying and standardizing the technology for future deployments.
Promotional text: The new generation of automatized samplers.

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

P3.1-302 – 4-Mode GNSS Solution to OSI

Author: Fuliang Chen[1]
Co-authors: Chao Xue[1]; Xinmin He[2]; Yang Xu[2]; Xue Hang[2]; Peng Li[2]
[1]*Space Star Technology Co. Ltd., Beijing, China*
[2]*Hope Investment Development Corp. Ltd., Beijing, China*
Corresponding Author: chenfl@spacestar.com.cn

Positioning and navigation are essential for inspectors in the Inspection Area, which is probably a place of nowhere in the world. They would lead the inspectors to the potential Ground Zero together with the guidance of OSI search logic. They are also very important for most of the OSI measurements, which are normally geo-referenced, such as SAMS, CPT, multispectral imaging. With the development of global satellite navigation system, including GPS, GLONASS, GALILEO, BEIDOU, GNSS has already been a technical solution, which makes it possible to take advantages of all the existing major satellite navigation systems. This work would propose a 4-mode GNSS solution to OSI, which is compatible with all the existing satellite navigation systems and more reliable. It would also keep the balance of mission sufficiency and political awareness. Any of the GNSS system receiving channel could be blinded according to the ISP requirement out of the negotiation between IT and ISP during the future OSI. This system is designed to meet with field mission. Android system based hand-held tablet has a user-friendly interface, which would integrate more software applications meeting with inspectors' customized requirements. It would also be very easily to be connected through network with OSI IIMS system.

Promotional text: This work carried out a study on 4-mode GNSS solution for OSI, which would provide an option for OSI positioning and navigation while keeping the balance of mission sufficiency and political awareness.

P3.1-303 – Coincidence Detector System Configurations for Particulate Stations of the IMS Network

Authors: Richard Britton[1]; Barbara Nadalut[1]; Ashley Davies[2]; Nikolaus Helmut Hermanspahn[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*AWE Aldermaston, Reading, United Kingdom*
Corresponding Author: richard.britton@ctbto.org

Coincidence Detector Systems have the potential to increase IMS network sensitivity for Treaty Verification purposes. The study presents the first test implementation of a coincidence detector system for measurement of particulate samples at the CTBTO Test Station VIP00, located on rooftop of Vienna International Centre in Vienna – Austria. The prototype dual/coincidence system setup and its configuration are built upon previous coincidence systems developed at GBL15 (AWE, Aldermaston, United Kingdom), and are part of an ongoing collaboration between the Commission and AWE investigating the potential of these systems to enhance the quality and sensitivity of measurements performed at Radionuclide Stations within the IMS network.

Promotional text: Advanced (operational) coincidence systems for particulate monitoring are in use at several CTBTO laboratories. These systems have the potential to greatly improve the sensitivity of measurements and are being evaluated for deployment on the IMS.

P3.1-309 – Development of a First-Look Cadmium Zinc Telluride Detector for the Radionuclide Aerosol Sampler Analyzer

Authors: Jonathan Burnett[1]; Ian Cameron[1]; Shaun Little[2]; Matthew Wright[2]; Allan Myers[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
[2]*General Dynamics Mission Systems (GDMS), Chantilly, VA, USA*
Corresponding Author: jonathan.burnett@pnnl.gov

A novel first-look cadmium zinc telluride (CZT) detector is being developed by Pacific Northwest National Laboratory (PNNL, USA) in collaboration with General Dynamics – Mission Systems (GDMS, USA). The compact gamma-spectrometer is designed to be installed within the air intake plenum of the Radionuclide Aerosol Sampler Analyzer (RASA) design of International Monitoring System (IMS) radionuclide stations. It provides real-time measurements of the radionuclides collecting on the filters in advance of the standard High-Purity Germanium (HPGe) measurement made 48 – 72 h after sample collection. These measurements are made every 15 minutes, and may provide an early indication of radionuclides relevant for Treaty monitoring purposes, supporting nuclear event discrimination and atmospheric transport modelling (ATM) projections. During the high-activity conditions that might be expected during a nuclear accident, it would also provide a measurement of dose rate useful for protecting the station operator and other personnel (including the dose expected from activity collected on the filters). The first-look detector would also safeguard against contamination of the RASA, and may be used to trigger reduced air flow and collection time, to limit the activity being collected onto the filters, and measured by the HPGe.
Promotional text: The first-look CZT detector aims to advance the capabilities of the radionuclide monitoring stations of the IMS. It is aligned to Theme 3: Verification Technologies and Technique Application – Design of Sensor Systems and Advanced Sensor Technologies (T3.1).

P3.1-312 – Development of an Ultra-Sensitive Gamma–Gamma Coincidence System for Radionuclide Measurements at International Monitoring System Stations

Author: Manish Sharma[1]
Co-authors: Troy Anderson[2]; Jonathan Burnett[1]; Lance Lidey[1]; Harry Miley[1]; Henrik Persson[2]; Kara Phillips[2]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
[2]*Mirion Technologies, USA*
Corresponding Author: mksharma@pnnl.gov

Next-generation gamma-gamma coincidence measurements have the potential to significantly improve the confidence of detection of particulate radionuclides relevant for nuclear explosion monitoring purposes. Sophisticated laboratory systems have demonstrated order-of-magnitude improvements for radionuclides such as Ru-106/Rh-106, Cs-134 and Ce-144. However, the implementation of these systems at IMS particulate stations has been limited by the complexity of acquisition hardware, data processing and analysis techniques required. At Pacific Northwest National Laboratory (PNNL, USA), in collaboration with Mirion Technologies (USA), a prototype system suitable for station deployment is being developed. Designed for practical implementation and operation, the system consists of acquisition electronics that are compatible with the existing station hardware and streamlined software capable of calculating the activity of relevant radionuclides using coincidence algorithms. This presentation discusses the design, validation and performance of the system, and compares the detection sensitivity with standard IMS stations.
Promotional text: The next-generation gamma-gamma coincidence system aims to advance the capabilities of IMS radionuclide monitoring stations. It is aligned to Theme 3: Verification Technologies and Technique Application – Design of Sensor Systems and Advanced Sensor Technologies (T3.1).

P3.1-375 – The Swedish Radioxenon CUBE Array – Operational Experience and First Data

Authors: Anders Axelsson[1]; Anders Ringbom[1]; Catharina Söderström[1]; Henrik Olsson[1]; Johan Kastlander[1]; Klas Elmgren[1]; Mattias Aldener[1]; Tomas Fritioff[1]
[1]*Swedish Defence Research Agency (FOI), Stockholm, Sweden*
Corresponding Author: anders.ringbom@foi.se

The worlds first radioxenon array was installed in Sweden during 2020-2021. The array consists of five so called SAUNA CUBE units, placed with 200 – 500 km inter-distance. Each CUBE unit has a measurement sensitivity for 12-hour samples comparable to the SAUNA II systems presently used in the IMS, but to a fraction of the cost. Array design, experiences from installation, and first months of operation of the array will be reported, as well as analysis of array data compared to data collected by a next generation SAUNA III system simultaneously running in Stockholm.
Promotional text: This is the first test of a new, unique concept in radioxenon detection, that has the potential to advance the field of radioxenon verification substantially.

P3.1-393 – The Second Generation of Precision Small-Sized Temperature Sensors: Measurement and Taking Account of the Internal Temperature of Seismic Instruments

Author: Valentin Gravirov[1]
Co-authors: Dmitry Likhodeev[1]; Konstantin Kislov[2]
[1]*Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Russian Federation*
[2]*Institute of Earthquake Prediction Theory and Mathematical Geophysics (IEPT RAS), Russian Federation*
Corresponding Author: gravirov@mail.ru

One of the main noise-causing factors in precise long-period seismometry is temperature fluctuations of mechanical elements of devices and sensitive sensors, as well as temperature oscillations in their interior space. To reduce such noise level it is possible to apply adaptive filtering of seismic signal based on elements temperature acquisition. However, to date, this way it was not possible to achieve significant results since there were no small systems capable of recording temperature changes with sufficient accuracy. The developed precision small-sized temperature sensors are capable of simultaneously monitoring the temperature at several of the most important points of many seismic device with an accuracy of at least about 0.001 Celsius degrees.
Promotional text: One of the main noise-causing factors in precise long-period seismometry is temperature fluctuations of mechanical elements of devices and sensitive sensors. To reduce such noise level we promise to use our precision small-sized temperature sensors.

P3.1-394 – The Second Generation of Precision Small-Sized Temperature Sensors: Investigation of Thermal Fields Near the Elbrus Volcano on the Basis of the North Caucasus Geophysical Observatory

Author: Valentin Gravirov[1]
Co-authors: Dmitry Likhodeev[1]; Konstantin Kislov[2]
[1]*Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Russian Federation*
[2]*Institute of Earthquake Prediction Theory and Mathematical Geophysics (IEPT RAS), Russian Federation*
Corresponding Author: gravirov@mail.ru

The Baksan Neutrino Observatory of the Institute for Nuclear Research of the Russian Academy of Sciences is a unique engineering facility, which is a system of underground mine workings in the Andyrchi mountain massif (at a depth of 2 km from the surface and 4 km from mine enter) located twenty kilometers from the Elbrus volcano down the Baksan gorge in the Neutrino village. The unique location of the laboratory allows for a comprehensive analysis of various geophysical fields recorded in an almost complete absence of interference.

Precision temperature measurement provides quantitative information about the heat flow from the interior of the Earth, which is fundamental for a deeper understanding of the relationship between fluid-magmatic and geodynamic processes. It allows obtaining unique data on the structure and dynamics of the thermal field of the Elbrus volcano. This study is a particularly important task from the point of view of obtaining new fundamental knowledge about the structure of magmatic structures, and from the point of view of assessing the volcanic hazard caused by the presence of liquid magmatic melt in the interior of the volcano, which in turn will provide new data on the potential hazard of the Elbrus volcanic center.
Promotional text: The system of precision temperature measurements, developed at the IPE RAS, is a part of the North Caucasus Geophysical Observatory of the IPE RAS. It allows obtaining unique data on the structure and dynamics of the thermal field of the Elbrus volcano.

P3.1-396 – Ice Geo-Hydroacoustic Buoy: First Field Test Results

Author: Valentin Gravirov[1]
Co-authors: Dmitriy Presnov[1]; Ruslan Zhostkov[1]
[1]*Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Russian Federation*
Corresponding Author: gravirov@mail.ru

In recent years, a new prototype of a geo-hydroacoustic buoy has been created at the IPE RAS. The buoy is designed to collect acoustic, hydroacoustic or seismoacoustic data in various environmental conditions. It can be installed in onshore and offshore wells. The main purpose of the buoy development was its use for operations in the Arctic latitudes as an element of distributed drifting ice-class antennas. These buoys can be suitable for IMS station in Polar conditions. The buoy is built on a modular structure and can include a combination of sensors: a vector scalar hydroacoustic accelerometer, a broadband molecular electronic velocimeter, and additional hydrophones. A significant advantage of the buoys is their robust case, which allows them to be used on ice fields and under water at depths of up to 300 meters. They can be moving without special handling, which is especially important when transporting by such special means as boats, helicopters, etc. The advantage of the buoy is its low power consumption, which ensures stable autonomous operation for at least one week. Recently, several field tests of buoys have been carried out, during which it was confirmed that they fully meet the high standards of modern seismological instruments.
Promotional text: In recent years, a new prototype of a geo-hydroacoustic buoy has been created at the IPE RAS. The main purpose of the buoy development was its use for operations in the Arctic latitudes as an element of distributed drifting ice-class antennas.

P3.1-434 – Upgrading the Detection System of the MIKS (TKAS6) Xenon Isotope Monitoring Complex During Preparation for the International Certification

Author: Mikhail Chernov[1]
Co-authors: Nadezhda Goryacheva[1]; Maksim Orlov[1]; Vasiliy Probylov[1]; Nikolay Sidorov[1]; Dobrynya Timofeev[1]; Daniil Molodtsev[1]; Oleg Tkachev[1]; Oleg Gerasimchuk[1]; Damir Ergashev[1]
[1]*All-Russia Research Institute of Automatics named after N. L. Dukhov (VNIIA), Moscow, Russian Federation*
Corresponding Author: myuchernov@hotmail.com

The initial version of the beta-gamma coincidence detector of the MIKS complex failed to meet the requirements specified by the PTS of the CTBTO Preparatory Commission for the energy resolution of the beta channel and the memory effect. After the substantial upgrading, the energy resolution of the beta channel of the redesigned detectors is 37–38 keV for the 129 keV line and the memory effect does not exceed 3%, which meets the PTS requirements. The container of the QC source has been replaced with a container that is more transparent

for gamma rays. The tests of the upgraded detection system of the MIKS complex prototype, the analysis of the data files transferred by VNIIA to the IDC based on the test results, and the prompt implementation of the PTS recommendations by VNIIA confirm the readiness of the MIKS (TKAS6) xenon isotope monitoring complex for its certification in the International Monitoring System. In order to successfully certify the MIKS complex taking the remoteness of its location (IMS RN58 Station near Ussuriysk, Primorsky krai of the Russian Federation) into account, VNIIA will provide prompt response to any undesirable event during the certification operation of the MIKS complex.
Promotional text: The process of development and modernization of a detection device for a radioactive xenon detection system based on the beta-gamma coincidence method is described.

P3.1-485 – Measurement of Gaseous Fission Products on an Electron–Photon Coincidence Detector System

Authors: Matthew Goodwin[1]; Steven James Bell[2]; Ashley Davies[1]; Richard Britton[3]; Sean Collins[2]; Robert Shearman[2]; Patrick Regan[4]
[1]*AWE Aldermaston, Reading, United Kingdom*
[2]*National Physical Laboratory (NPL), Teddington, United Kingdom*
[3]*CTBTO Preparatory Commission, Vienna, Austria*
[4]*University of Surrey, Guildford, United Kingdom*
Corresponding Author: matthew.goodwin@awe.co.uk

Gaseous fission products have been produced via neutron irradiation of a uranium target and extracted using a custom gas processing system for measurement on a high-resolution beta-gamma coincidence detection system. The gas was extracted and measured in two stages in order to measure the prompt and delayed fission products. This poster presents an overview of the system used to extract gaseous products, and the results of the advanced coincidence techniques used to identify and quantify the radionuclides present. This work demonstrates the capability to produce gaseous radionuclides for quality assurance and calibration purposes in Radionuclide Laboratories supporting the Comprehensive Nuclear-Test-Ban Treaty (CTBT) as well as for the calibration of equipment used for criticality monitoring.
Promotional text: Fission product gases have been produced, processed and measured on a high resolution beta-gamma coincidence spectrometry system. Results from the measurements are presented.

P3.1-495 – Analysis and Design of Wide Spectral Imaging Spectrometer for CTBT OSI

Author: Peng Li[1]
Co-authors: Haoyang Li[2]; Xinmin He[1]; Lijin Li[2]; Bicen Li[2]; Weigang Wang[2]; Xue Hang[1]; Yupan Shi[2]
[1]*Hope Investment Development Corp. Ltd., Beijing, China*
[2]*Beijing Institute of Space Mechanics & Electronics, Beijing, China*
Corresponding Authors: si_fi@163.com, lipeng1406@163.com

According to scenarios of Comprehensive Nuclear-Test-Ban Treaty On Site Inspection (CTBT OSI), a kind of wide spectral imaging spectrometer based on aviation platform (including UAV) is proposed. The methods of detecting and recognizing nuclear test based on optical remote sensing are summarized, and several application fields using hyper spectral data are analyzed, such as detecting the changes of geography, landform and its spectrum, as well as plant stress. Aiming at the analysed features, single grating is adopted to realize highly compact design of the spectrometer, which has wide spectrum range from VIS to MWIR (0.4μm -5μm) with high SNR (1000). Based on the further study and comprehensive discussion with the experts in the field of nuclear test inspection, we expect to upgrade the spectrometer for a better application.
Promotional text: According to scenarios of CTBT OSI, a kind of wide spectral imaging spectrometer based on aviation platform (including UAV) is proposed in this paper which can be used for detecting and recognizing nuclear test, expanding methods of CTBT OSI.

P3.1-506 – Large Surface Detector System for the Contamination Evaluation of Air Filters

Authors: Erica Fanchini[1]; Massimo Morichi[1]
Co-author: Matteo Corbo[1]
[1]*CAEN S.p.A., Viareggio, Italy*
Corresponding Author: e.fanchini@caen.it

The system is an alpha/beta detector able to determine the independently alpha and beta contaminations based on PSD (pulse shape discrimination) capabilities of the scintillator and the real time digital pulse processing of fast electronic readout. The detector is designed for measuring alpha and beta emitter contamination on large air sampling filters and to complement the high-resolution spectrometry of gamma radiation. The detector is based on a ZnS scintillator with a sensitive surface of 576 cm^2 and an active area of more than 97%, that can be customizable. It is embedded in a shielding structure to reduce the external background and radiological content coming from other filters located nearby. The system was laboratory tested with the procedure used for contamination monitors based on large area radioactive sources to verify its functionality and the uniformity for both alpha and beta sources. Results demonstrate a good response to the different source energies and over the full area. The signal discrimination analysis used, electronics, software, test procedure and measurements performed will be described.
Promotional text: The system exploits digital pulse processing to identify beta and alpha radiation with large surface detectors and rejects cosmic radiation background. This detection system could be integrated in the CTBTO gamma monitoring stations, for an additional assay of the air filters.

P3.1-512 – Past and Future Developments of Noble Gas Detection Systems at CEA/DAM

Authors: Sylvain Topin[1]; Philippe Gross[1]; Antoine Cagniant[1]; Olivier Delaune[1]; Thomas Philippe[1]; Jean-Pierre Fontaine[1]; Guilhem Douysset[1]; Gilbert Le Petit[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: sylvain.topin@cea.fr

For several decades, CEA/DAM is developing noble gas detection systems for nuclear test detections. In particular, CEA/DAM developed the SPALAX system which started to integrate the CTBTO IMS network in Tahiti in 2002. In 2015, CEA/DAM started the conception and realization of the SPALAX New Generation (SPALAX-NG) integrating the results of several years of R&D on material adsorbents and electron/photon detectors. The first industrial system has been released in 2017 and is currently finalizing its qualification by PTS. In its continuous effort of R&D, CEA/DAM is already prospecting for the next generation technologies. This presentation aims to provide an overview on the past, recent and future developments for noble gas detections at CEA/DAM.
Promotional text: Past and future development in radioxenon detection at CEA/DAM.

P3.1-520 – Design of Wind Noise Reduction System and Technique Application

Author: Clement Bednarowicz[1]
Co-author: Bastien Vanderstraeten[1]
[1]*Enviroearth, Saint-Cannat, France*
Corresponding Author: c.bednarowicz@enviroearth.fr

Enviroearth has developed over the past few years Wind Noise Reduction System (WNRS) of advanced technologies that meet all the requirement and configuration for each of the infrasound stations topology over the whole IMS Network. Among the continuous improvements made to the design of these systems systematically associated with micro barometer sensors, we will mainly present the possibility of verifying the correct installation of our WNRS by carrying out a pressure test regardless of the WNRS model installed. In addition, we will introduce the reference system technology developed by Enviroearth. The objective being to compare the signal received by a sensor connected to a standard WNRS in parallel to a sensor connected to a reference system and thus to make analysis and verification on the corresponding signals received. The studies carried out on the comparison of these 2 signals provide rich information in terms of verification method as well as analysis of spectra and events.

Promotional text: Over several years Enviroearth has been working on optimizing its WNRS by supplying and deploying systems on IMS infrasound sites. Therefore, we continuously improve the design of our products to best suit the CTBTO needs and would like to share all our corresponding knowledge.

P3.1-524 – Timing Board: A New Module for Very Low Consumption Timing Applications

Author: Jean-Christophe Lictevout[1]

[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*

Corresponding Author: jean-christophe.lictevout@cea.fr

CEA/DAM, in partnership with the startup Fullscale, has developed a compact board, targetted to easily integrate any equipment with accurate dating needs. Based on GNSS reception to get an absolute time reference anywhere in the world, the Timing Board provides standard PPS signal and NMEA frames, and optionnally a stabilized 4 MHz clock. Its extra small size and very low consumption (<40 mW) allow it to be embedded in any kind of device, such as compact digitizers or digital sensors. The Timing Board module offers a very high stability without GNSS reception: the maximum drift is +/- 20 ppb over a wide temperature range [-20°C; +70°C]. This module meets the PTS requirements in terms of timing and will be integrated in SMAD and MB3d digitizers soon.

Promotional text: Timing Board: a new module for very low-consumption timing applications with very high accuracy.

P3.1-527 – Tests and Performance of a Special Identifier of Nuclear Threats and SNM in Realistic Scenarios

Authors: Giacomo Mangiagalli[1]; Massimo Morichi[1]; Isacco Bonesso[2]; Luca Stevanato[2]

Co-author: Matteo Corbo[1]

[1]*CAEN S.p.A., Viareggio, Italy*

[2]*University of Padua, Padua, Italy*

Corresponding Author: g.mangiagalli@caen.it

This paper presents the results of extensive tests conducted for more than 4 years, towards the realization of a portable backpack systems for the measurement and identification of radioactive material and at the same time determine in real time, without the support from experts, presence of SNM isotopes: U, Pu-239, PuWG, UWG, Am-Be, Am-Li, or their combination with masking sources and shielding. The performances of the device are exceeding the reference standards in sensitivity and furthermore for its capability SNM identification. The exclusive feature of this instrument is the capability to discriminate between fission sources (like Californium 252Cf) and alpha-n type sources (like Americium Beryllium Am-Be) from Plutonium and Uranium through an innovative dedicated parallelized algorithm. The neutron source detection has also been proved in a gamma ray field up to 100-300 μSv/h. This device, based on an organic liquid scintillator with excellent Pulse Shape Discrimination (PSD) proprieties for the simultaneous detection of gamma rays and neutrons, detects radioactive source as SNM, medical, industrial and Naturally Occurring Radioactive Material. An additional inorganic scintillator is also embedded, giving the capability of calculating Pu and U enrichment grade through characteristic gamma emission lines.

Promotional text: The system presented can perform the characterization of nuclear and other radioactive materials using a combined detection of fast neutrons and gamma radiation that can help to determine the origin and history of the materials under assay.

P3.1-616 – Xenon International Acceptance Test Phase 1

Authors: James Hayes[1]; Matthew Cooper[1]; James Ely[1]; Warren Harper[1]; Justin McIntyre[1]; Mark Panisko[1]; Michael Robert Howard[2]; Kevin Carter[2]; Tricia Gomulinski[2]; Robert Mikulyak[2]; Aaron Orr[2]; Ryan Sayne[2]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
[2]*Teledyne Brown Engineering, Inc, Knoxville, TN, USA*
Corresponding Author: jc.hayes@pnnl.gov

Xenon International is a next generation radioxenon monitoring system that was developed at PNNL and being manufactured at Teledyne Brown Engineering (TBE) to strengthen nuclear test monitoring and has recently completed phase-1 testing for acceptance as a qualified system for the International Monitoring System (IMS). Xenon International processes samples every 6 hours generating over 2.5 cc of xenon gas that is counted in a beta-gamma coincidence detector for 12 hours resulting in unprecedented detection limits for radioxenon isotopes. Phase 1 testing was conducted at TBE and consisted of a PTS acceptance visit, radioxenon spikes processed on Xenon International, and 6 months of uninterrupted automated sampling and analysis. Radioxenon analysis data was automatically sent to the PTS after the finish of each count. Xenon International completed phase 1 testing with >98% uptime, and routinely detected never-before seen radioxenon isotopes in an IMS station including ^{125}Xe, ^{127}Xe, and ^{129m}Xe. This talk will discuss Xenon International performance during phase-1 testing and will discuss the impact of unexpected radioxenon isotopes on detection of treaty verification radioxenon radionuclides.
Promotional text: The work cited in this presentation fosters strengthening nuclear test monitoring though development of advanced radionuclide detection systems. Phase 1 testing also strengthens remote monitoring of nuclear explosion, data interpretation, and data availability of complex systems.

P3.1-618 – Ukrainian Infrasound Network: Current State and Short-Term Perspective

Authors: Oleksandr Liashchuk[1]; Leonid Kolesnykov[2]; Yuriy Andrushchenko[1]; Evheniy Kariagin[1]; Ivan Tolchonov[1]; Anatoliy Poichalo[1]
[1]*Main Centre of Special Monitoring, State Space Agency of Ukraine, Godorok, Ukraine*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Authors: alex_liashchuk@ukr.net, leonid.kolesnykov@ctbto.org

Until recently, the infrasound network in Ukraine consisted of two infrasonic arrays with a small aperture. However, the situation changed when we managed to create our own inexpensive digital condenser microbarograph (DCM). It has a frequency range of 0.05 to 15 Hz, a sensitivity of 40 mV/Pa, and an amplitude range of 200 Pa. Now, the array in the Kamenets-Podilsky region consists of 8 microbarographs. The array near Malin consists of 3 elements. The infrasound array near Radomyshl was created from 4 microbarographs in 2020. A site has been prepared for placing a three-element array in the Luhansk region (next Odesa region). The tests of microbarographs on the PS45 seismic station elements have also been successfully carried out and the installation of 7 microbarographs is planned. For research purposes, a 3-element mobile array is available. The infrasonic microbarograph at Vernadsky station (Antarctica) is supplemented with a set of 4 Chaparral Model 64 microbarographs. All data in miniSEED format are collected at the NDC. A cloud service has been created for remote work with infrasonic data. The modernized network is a big step towards ensuring the implementation of the CTBT Treaty by national means. It is also a good tool for regional observations.

Promotional text: Infrasound technologies, which are developing at the national level, are an important part of the provisions of the CTBTO Treaty. By developing the national network, Ukraine contributes to the improvement of monitoring.

P3.1-642 – Levels of Background Seismic Noise in Venezuela with an Emphasis on the AS117 and AS118 IMS Stations

Author: José Tomás Del Castillo[1]
Co-authors: Michael Schmitz[2]; Herbert Francisco Ernesto Rendon Rodriguez[1]
[1]*Fundación Venezolana de Investigaciones Sismológicas (FUNVISIS), Caracas, Venezuela*
[2]*Universidad Simón Bolívar (USB), Caracas, Venezuela*
Corresponding Author: josetdcm@gmail.com

The background seismic noise in Venezuela has been studied using broadband stations of the Red Sismológica Satelital Nacional (RSSN) (Netcode VE), including stations AS117 and AS118 of the auxiliary network of the IMS. To calculate the most representative values of noise at a given period, the method proposed by McNamara and Buland (2004) has been applied. For periods lower than 1 s, the AS118 station shows values of -131.5 dB, while AS117 shows values of -121.5 dB. This 10 dB difference is attributed to the continuous discharge of water from the dam where AS117 is installed. For periods longer than 30 s, the vertical component of AS117 presents noise values close to the NLNM proposed by Peterson (1993), while the horizontal components present a sharp increase in noise values. The exact opposite behavior occurs in station AS118. An interpolation of the noise values was generated in the range 4 - 8 s (double frequency peak) where high noise values were observed in basins and low values in mountain ranges. The results obtained are important for studying the behaviour of the stations and detecting equipment failures. In addition, we show the behaviour of noise sources in Venezuela.
Promotional text: The results obtained in this study are important to understand the behavior of the IMS seismic stations in Venezuela. This study uncovers important information for the analysis of background noise collected by these auxiliary sensors.

P3.1-665 – Resolving Complex Infrasound Wavefields Using a Dense Array

Authors: Jacob Anderson[1]; Jeffrey Johnson[1]
[1]*Boise State University, USA*
Corresponding Author: ajakef@gmail.com

Complex infrasound wavefields (containing multiple simultaneous waves with different slowness vectors) pose a challenge for traditional array analysis. We approach this problem using a dense array (22 sensors) as a field method, and secondary infrasound from earthquakes as a research target. Secondary infrasound from earthquakes contains potentially useful information on ground shaking, but the presence of many interfering waves from different radiators complicates source analyses. Using both direct waves from a local earthquake (M3.5, 10 km) and refracted waves from a regional event (M6.5, 720 km), we show that the detail and resolving power provided by array analyses can be improved dramatically by increasing the number of sensors in the array. Many routine applications of infrasound face the challenge of distinguishing wave sources of interest from superposed waves from many sources, and single-channel rapid-deploy instrumentation suitable for “large-N” recording is increasingly available (e.g., the Gem infrasound logger used in this work). Consequently, we expect our methods and findings to be broadly applicable beyond our specific problem of earthquake infrasound.
Promotional text: Adding more sensors to infrasound arrays increases their resolving power, facilitating detection of weak signals and identification of multiple simultaneous waves from different directions.

P3.1-666 – Fiber-Optic Gyroscope to Catch Ground Motion: A Short Review of blueSeis Use

Authors: Frédéric Guattari[1]; Pierrick Auregan[1]; Théo Laudat[1]; Elliot de Toldi[1]
[1]*iXblue, France*
Corresponding Author: frederic.guattari@ixblue.com

For the past 3 years, rotation of ground motion can be measured with a portable broadband instrument. Thanks to its expertise in fiber-optic gyroscope learn into navigation market, iXblue have been able to offer a product line called blueSeis to bring the unmatched performance of this technology from submarines to seismic field. However, not everything has been straightforward, and there is still margin for improvement. So, in this presentation the most important failures that occurred during this short story will be described. Indeed, shortcomings are usually the best way to get to know someone or something better. Early adopters are also discoverers, and the main papers and results from the use of blueSeis sensors will be summarized here to give a broad overview of what can be done with this brand new sensor. Finally, the next steps for the development of the blueSeis product line will be revealed with the very first experimental test results of our upcoming product, which will have improved sensitivity.

Promotional text: Rotation of the ground can be measured now thanks to the fiber-optic gyroscope. This poster will share the story of the use of this brand-new instrument offered by iXblue, and share some information about future development.

P3.1-669 – Electrostatic Precipitator Integration into RASA 2.0 for Radionuclide Particle Collection

Authors: Michael E. Swanwick[1]; Clive Devoy[1]; Sheldon Stokes[1]; Jessica Elliott[1]; Katharine Fergusson[1]; Elizabeth McTighe[1]; Patrick Magari[1]
[1]*Creare LLC, Hanover, NH, USA*
Corresponding Author: swanwick@creare.com

Creare has previously designed an electrostatic precipitator (ESP) collection system as a drop-in enhancement and replacement for the current RASA, the U.S. built Radionuclide Monitoring Station, as presented at S&T2019. This current work incorporates a full new design for the next generation of monitoring stations, RASA 2.0, with several significant improvements including advanced detectors, increased particle collection efficiency, lower power consumption, and potentially shorter collection times. The ESP incorporates a new form factor, potential for new collection material, and improved integration into advanced detectors. Our advanced two stage ESP has shown greater than 90% particle collection efficiency at both 0.2–0.3 μm and 10 μm particle sizes for 2000 m^3/hr flow rates using 1443 W of ESP and blower power. The power consumption is almost 10x lower than the current impact filter RASA system at that same nominal flow rate of 1000 m^3/hr, and also consumes less power at 2000 m^3/hr than the current system at 1000 m^3/hr—approximately 25% lower. The ESP can be dynamically and remotely controlled to change the particle collection efficiency within seconds from less than 50% to greater than 95% efficiency depending on the conditions and needs of the users.

Promotional text: This work advances the radionuclide particle collection and detection by developing an electrostatic precipitator for the next generation of monitoring stations that will directly benefit CTBTO's radionuclide stations in the International Monitoring System.

P3.1-670 – Study of Materials for Improved Adsorption of Xenon at IMS Radionuclide Stations

Authors: Christophe Gueibe[1]; Jos Rutten[1]; Johan Camps[1]; Nikolaus Helmut Hermanspahn[2]
[1]*Belgian Nuclear Research Centre (SCK CEN), Mol, Belgium*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: christophe.gueibe@sckcen.be

Xenon monitoring systems are a crucial component of the verification system of the CTBT. As part of the IMS, these systems are monitoring the atmosphere for potential xenon releases originating from nuclear explosions. The efficient adsorption and desorption of the xenon isotopes in adsorbent materials is essential for their detection. Recent studies on xenon adsorption in porous materials have shown promising results for possible use in the IMS noble gas systems. In the framework of the two previous EU Joint Action programs, SCK CEN developed a laboratory set-up to perform breakthrough experiments on different adsorbent materials and developed a model for the simulation of the adsorption process. Although this research was performed in a different context, it was obvious that the studies performed and the methods developed could be beneficial also for xenon monitoring purposes. The SCK CEN has been contracted by the CTBTO under the EU JA VII program to perform a fundamental comparative study of xenon adsorption materials which, depending on the results, may be used for future alternatives for noble gas monitoring at IMS stations with the aim of higher detection capability. The project was completed end of 2020 and the results will be presented.

Promotional text: During this project, new Xe adsorption materials were investigated for potentially improving or providing future alternatives to current IMS noble gas systems with the aim to enhance the detection capability of the noble gas component of the IMS.

P3.1-713 – A Coherent Gas Combustion Infrasound Source

Authors: Chad Smith[1]; Thomas Gabrielson[1]
[1]*Pennsylvania State University, PA, USA*
Corresponding Author: cms561@psu.edu

An invaluable tool in characterization of any receiver, propagation path, or detection system, is a source with known and repeatable signal characteristics. This talk will discuss engineering development and evaluation of a coherent (non-explosive, periodic, with controlled duration) infrasound source with frequency capabilities in the sub-hertz to several hertz band. Design of a sound source within this band is a difficult engineering challenge. The simple source equation, which will govern any portable human-fabricated infrasound source due to the long wavelengths, shows this fundamental difficulty. As frequency decreases volume displacement must increase by the squared inverse factor of frequency in order to maintain an equal pressure amplitude at equal range. For this reason, the authors evaluate utilizing the high energy density available in gas combustion to periodically displace large volumes of air within the open atmosphere. Prototype testing has verified the capability of generating continuous signals at a fundamental frequency of 0.25 Hz at ranges >1 km in low wind conditions. Generation of harmonics of this fundamental throughout the 0.25-4.0 Hz band with reasonable signal-to-noise ratio was also demonstrated. These results will be reviewed, and efforts to increase useful source range will be discussed.

Promotional text: Development of a cost effective and transportable non-explosive infrasound source to aid in verification of infrasound monitoring sites.

T3.2 Laboratories Including Transportable and Field Based Facilities

Highlights

OSI Field Laboratory

O3.2-654 presented challenges for the measurement of ^{37}Ar, which is one of the isotopes that can provide conclusive evidence of a nuclear test during an OSI. Because traditional counting technology fails to achieve the required sensitivity, the Khlopin Radium Institute (Russian Federation) has been developing a measurement system for ^{37}Ar that uses liquefied argon as a liquid scintillator, thus overcoming limitations in sample size. The laboratory prototype has shown significant improvement in detection sensitivity.

Improvements to field-capable xenon detection systems for OSI were reported. P3.2-424 presented a significantly improved OSI radioxenon processing system (XESPM-III Mark II) developed by the Northwest Institute of Nuclear Technology (China). P3.2-518 presented a commercial containerized field-capable xenon detection system based on the SPALAX-NG measurement system that was developed by CELEGEC (France).

P3.2-691 summarized the layout and design of the next-generation OSI field laboratory. It highlighted the current status and future improvements and assessed the configuration of the field laboratory with regard to the specific requirements for measuring OSI-relevant xenon and argon isotopes.

IMS Laboratories

In O3.2-218, PNNL (USA) reported on the stability of the noble gas measurement system of radionuclide laboratory RL16 (USA). The performance of the system has been monitored for several years as part of routine laboratory quality assurance. Monitoring data showed that measures to ensure stable operation were highly effective, as the system has demonstrated excellent stability over many years, thereby increasing confidence in laboratory measurement results.

O3.2-482 compared the performance of different xenon detection systems at RL15 (United Kingdom). A high resolution beta–gamma detection system showed improved discrimination and reduced interference compared with the low resolution beta–gamma system currently in operation. Based on performance data from these two systems, the laboratory plans to evaluate a system with a combination of low resolution gamma–high resolution beta, offering high detection efficiency for gamma radiation and good separation of beta/electron emissions.

Proficiency test exercises not only provide performance evaluation of IMS laboratories, but can also provide additional tools for laboratories to improve the quality of their analysis. This includes the statistical evaluation of zeta test scores and the evaluation of measurement data including interferences. P3.2-279 presented results on extracting information on uncertainties from zeta statistics and on applying a modified method for determining characteristic limits based on ISO 11929:3 (2019) to experimental spectra.

O3.2 Laboratories Including Transportable and Field Based Facilities Abstracts of Oral Presentations

O3.2-218 – Long Term Verification of Radionuclide Laboratory Gain and Efficiency Stability

Authors: Michael Foxe[1]; Theodore Bowyer[1]; Ian Cameron[1]; Matthew Cooper[1]; James Hayes[1]; Michael Mayer[1]; Jennifer Mendez[1]; Johnathan Slack[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: michael.foxe@pnnl.gov

As radioxenon samples are collected around the world at the CTBTO IMS stations, a subset of those are sent to radionuclide laboratories around the world for re-analysis. PNNL operates the U.S. Noble Gas Laboratory (US-NGL), which was certified in December of 2016. There is also an opportunity to utilize the radioxenon laboratories in a field system comparison experiment. In this presentation, we detail current and potential future methods of utilizing the radioxenon laboratories. For a laboratory system to be used for verification of continuously operating systems, it is important to routinely validate the energy and efficiency calibration of the laboratory system. We discuss long-term verification measurements made for USL16-NGL and the methods utilized to ensure stable operation. Additionally, we present the impact of the enhanced throughput on such scenarios and how to ensure that the operational role is maintained during experiments.

Promotional text: Long-term monitoring and verification of noble gas laboratories allows for improved confidence in the IMS data and analysis.

O3.2-482 – A High Resolution Laboratory Based Beta–Gamma Coincidence Spectrometry System for Radioxenon Measurement

Authors: Matthew Goodwin[1]; Ashley Davies[1]; Richard Britton[2]; Steven James Bell[3]; Sean Collins[3]; Patrick Regan[4]; Robert Shearman[3]
[1]*AWE Aldermaston, Reading, United Kingdom*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
[3]*National Physical Laboratory (NPL), Teddington, United Kingdom*
[4]*University of Surrey, Guildford, United Kingdom*
Corresponding Author: matthew.goodwin@awe.co.uk

GBL15, the UK's noble gas certified Comprehensive Nuclear-Test-Ban Treaty (CTBT) radionuclide laboratory supports the International Monitoring System (IMS) through measurement of environmental radioxenon samples using beta-gamma coincidence spectrometry. GBL15 currently utilizes a system comprised of NaI(Tl) photon detectors and plastic scintillator electron-detectors to measure coincident emissions from the four radioxenon isotopes of interest: Xe-133, Xe-135, Xe-131m and Xe-133m. A high-resolution electron-photon coincidence detector system comprising of high purity germanium (HPGe) detectors and a PIPSBox detector demonstrates improved discrimination between signals and less interference compared to the current system. The minimum detectable activities (MDA) and coincidence detection efficiencies for the radioxenon isotopes of interest have been quantified.

Promotional text: The UK CTBT Radionuclide Laboratory, GBL15, has configured a high-resolution beta-gamma coincidence detection system for laboratory radioxenon measurements. The system is benchmarked against the current certified capability.

O3.2-654 – Installation for the Measurement of Low Activities of ^{37}Ar Based on the Detection of Liquid Argon Scintillation

Author: Sergei Pakhomov[1]
Co-authors: Tatiana Kuzmina[1]; Ekateryna Kurysheva[1]; Gennady Shakhetov[1]
[1]*Khlopin Radium Institute, St. Petersburg, Russian Federation*
Corresponding Author: s_a_pakhomov@mail.ru

One of the most conclusive evidences of a violation of CTBT is the presence in the subsoil air of elevated concentrations of ^{37}Ar radionuclide, which is formed in large quantities in the interaction of neutrons with calcium in rocks. Traditionally, to measure the activity of ^{37}Ar, proportional gas counters are used, which are filled with a counting gas prepared from samples of argon with the addition of methane. Further reduction of the detection limit of ^{37}Ar is limited by the difficulty of a significant increase of argon sample volume placed in a proportional counter. Installation for the detection of argon-37 low activities based on the liquid scintillation principle was developed at the Khlopin Radium Institute under contract with the CTBTO. The role of the scintillator in this installation is performed by the liquefied preparation of extracted from soil air argon itself. The use of liquefied argon samples allows one to multiply the volume of the measured samples without increasing the size of the measuring cell and shield elements, and allows significant reduction of detection limits of ^{37}Ar. The presentation contains a description of the installation and the results obtained after its testing.

Promotional text: One of the main objectives of the conference is to identify opportunities and possible solutions for the continuous improvement of the control and verification of nuclear tests. The theme of our presentation is fully consistent with the achievement of this goal.

P3.2 Laboratories Including Transportable and Field Based Facilities Abstracts of Poster Presentations

P3.2-279 – Proficiency Test Exercises (PTE): Bringing Certainty into Uncertainty

Authors: Nikolaus Helmut Hermanspahn[1]; Herbert Gohla[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: nikolaus.hermanspahn@ctbto.org

The international monitoring network of radionuclide stations of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) is supported by 16 radionuclide laboratories. As part of a continuing performance evaluation programme for these laboratories PTEs have been organised for the particulate and noble gas measurement capabilities of the IMS laboratories. PTS has been evaluating additional tools to the standard PTE grading scheme to assist laboratories with improving quality of results. This includes the statistical evaluation of zeta test scores and evaluation of measurement data including interferences. One of the critical steps in analysing a gamma spectrum includes the decision on which nuclides are present in the sample. Statistical methods employed in standard commercial software for evaluating whether the measurement signal is consistent with background noise ignore complications that may arise from interfering radionuclides. We present results for extracting information on uncertainties from zeta statistics and of applying a modified method for determining characteristic limits based on ISO11929:3 (2019) to experimental spectra.

Promotional text: Proficiency Test Exercises not only provide performance evaluation of IMS laboratories, but can also provide additional tools for laboratories to improve the quality of their analysis.

P3.2-424 – Modification of OSI Radioxenon Processing System

Author: Chongyang Zhou[1]
[1]*Peking University, Beijing, China*
Corresponding Author: zhouchongyang@pku.org.cn

In order to play a more important role in the OSI activities organized by CTBTO, such as inspector training, the single technique test or exercise, build-up exercises (BUEs) and the OSI integrated filed exercise (IFE), et cetera, the Northwest Institute of Nuclear Technology (NINT) manufactured one brand new OSI radioxenon processing system (or XESPM-III Mark II). Comparing with the XESPM-III Mark I, four aspects of modifications have been made. First, sufficient amounts of switchable parts installed before each running can fulfill the aim of automatic processing without an attendant. Second, the refrigerating temperature has been lowered further to increase the sampling volume per trap due to the enlarged adsorption efficiency. Third, the processing volume is doubled to the amount of 8 m^3, consequently the least minimum detectable activity concentration (MDC) can be halved. Fourth, the processing time is shortened, so the daily processing throughput can be further increased. The technical specifications of XESPM-III Mark II has obviously been improved, such as more sensitive, faster in processing and more adaptable for field use, et cetera.
Promotional text: Three-generation OSI radioxenon systems have developed, and participated in some activities organized by PTS since 2002. In order to play more important role in the build-up exercise, one modified XESPM-III was manufactured, whose specifications have been improved a lot.

P3.2-518 – Introducing Mobile SPALAX NG Version

Authors: Axelle Gourgues[1]; Sylvain Topin[2]
Co-authors: Henri Chevreul[1]; Jean-Claude Piwowarczyk[2]; Thomas Philippe[2]; Gabriel Couchaux[2]; Laurent Dubois[1]; Frederic Tribet[1]
[1]*CEGELEC Defence, France*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: axelle.gourgues@cegelec.com

In the context of the Comprehensive Nuclear Test Ban Treaty (CTBT), the CEA/DAM developed the SPALAX (Système de Prélèvement Automatique en Ligne avec l'Analyse du Xénon) about 20 years ago which is used in the International Monitoring System to detect xenon releases following a nuclear explosion. The new generation of the system has been successfully developed by the CEA and CEGELEC Défence. It is now fully operational. For the second system, CEGLEC integrated the SPALAX NG modules in a shelter. This way, it can be deployed easily anywhere in the world. It is energy self-sufficient (generator) and can be supplied by different electricity networks. CEGELEC climate chamber reproduces extreme weather conditions and the tests of the SPALAX-NG shelter were very satisfying. It is now in service in France for the CEA experimentations.
Promotional text: The Spalax NG should be part of the IMS stations in the future. We wish we introduce the shelter version of the product.

P3.2-691 – Design Considerations and Layout of the New OSI Field Laboratory

Author: Robin Riedmann[1]
Co-authors: Xavier Blanchard[1]; Alana Campbell[1]; Mohamed Ali Nasri[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: robin.riedmann@ctbto.org

According to paragraph 69(d) of Part II of the Protocol to the CTBT, future OSI inspectors are permitted to analyse environmental samples from above, at and below the surface to detect anomalies. These analyses shall take place at the OSI field laboratory which must be designed for ready deployability, set-up and in-field operation. The OSI action plan for 2016-2019 aimed at improving and testing the design of the OSI field laboratory in general and the set-up and in-field operations for radionuclide noble gas sample processing and analysis in particular. The configurations of the field laboratory with due regard to the specific requirements for measuring OSI relevant xenon and argon isotopes were assessed. The approach taken comprised the preparation of a draft layout and design of the next generation OSI field laboratory from the perspective of the requirements for radionuclide noble gas sampling and analysis. This poster provides a summary of the layout and design of the next generation OSI field laboratory. It highlights the requirements, the current status and future improvements of the OSI field laboratory for the development of OSI capabilities.

Promotional text: The poster addresses the configuration requirements of the next generation OSI field laboratory, their status and future development and therefore contributes to the objective of identifying opportunities for improving verification.

T3.3 Remote Sensing, Imagery and Data Acquisition Platforms

Highlights

This topic addressed ground, air and space-borne remote sensing platforms and also focused on different types of sensors. In addition, several presentations addressed the processing of data acquired from sensors and how they can be used to strengthen the verification regime.

On the processing of imagery, presentations discussed a range of different sensors, both optical and radar. O3.3-117 focused on a tool that could be readily incorporated into activities at the Operations Support Centre during the launch phase of an OSI. The tool, which is built on a commercial GIS software package, automates image orthorectification and change detection of time series optical satellite imagery. Coupled with the change detection algorithm, this tool could highlight areas that warrant the attention of the inspection team. Also in the change detection field, O3.3-085 described the application of a semi-automated pixel–object fusion algorithm, and P3.3-586 used a pixel subtraction method for event verification. P3.3-132 described the use of radar technology for the identification of land deformation. Specifically, it reported on the use of differential interferometry synthetic aperture radar for the detection of land deformation. In general, these image processing methods could be advantageous during the launch phase of an OSI, as they could identify areas of interest and therefore contribute to the implementation of the inspection team functionality concept. However, these methods rely on the availability of relevant imagery acquired before and after the triggering event.

The application of microsatellites featured in two presentations. Without elaborating on specific sensors, P3.3-059 described the potential value of nanosatellite constellations for arms control verification, while P3.3-692 described how microsatellites could be used to determine tectonic events. In contrast, P3.3-023 described the value of infrasound sensors in a balloon constellation in the stratosphere.

The potential value of using UAVs during an OSI was highlighted in two presentations that built on a presentation given by the same group at SnT2019, which underlined the versatility of such platforms for near surface applications. O3.3-295 focused on a platform for a magnetic sensor, while P3.3-110, more generically, described a cost effective application during an OSI using a UAV as a platform to carry multispectral sensors. Both presentations emphasized that a UAV would have been valuable during the Integrated Field Exercises in 2008 and 2014 and capable of detecting magnetic anomalies with sensitivity ranging from 0.5 nT to 10 nT, with detection depth from 3 m to 60 m.

Finally, in the field of seismic geophysics, O3.3-153 described how in situ processing of geophysical data can be performed at remote locations, limiting the need to transfer data continuously to a central processing centre. In this way, seismic signals are classified at the remote site.

O3.3 Remote Sensing, Imagery and Data Acquisition Platforms Abstracts of Oral Presentations

O3.3-085 – Performance Evaluation of the Pixel–Object Fusion Algorithm for Change Detection in Use of Countering Nuclear Proliferation

Author: Jae-Jun Han[1]
Co-authors: Sang Wook Park[1]; Nam Kyung Kim[1]
[1]*Korea Institute of Nuclear Nonproliferation and Control (KINAC), Daejeon, Republic of Korea*
Corresponding Author: jjhan@kinac.re.kr

For countering nuclear proliferation, the structural changes within the suspicious area have to be carefully monitored. Due to the restriction of access to rogue states, the level of change is highly dependent on the spatial resolution of satellite imagery. As increasing the quality and quantity of the imagery, the semi-automated change detection process has been studied in support of the interpretation. Nonetheless, the availability of various methods rather focused on case studies, and the results are qualitatively discussed in general. In a practical perspective, ultimately the performance has to be reviewed quantitatively so that field users can understand usability and unusability of the semi-automated system. Further, it leads to how to supplement the state-of-art technologies for field use. With this background, this paper presents the change detection algorithm developed by Korea Institute of Nuclear Nonproliferation and Control (KINAC), which integrates pixel and object advantages in computer vision, and quantitatively evaluates the performance with accuracy indices. For the semi-automated change detection, incompatibility between the recall and false discovery rate is discussed numerically. It is concluded that effective threshold values for the semi-automated change detection can be derived from the optimisation perspective, although it must vary depending on the purpose of use.

Promotional text: The analysis techniques for satellite information for nonproliferation use have been discussed in the SnT conferences. A few states have undertaken their own R&D programme, and this is the first time to introduce the ROK programme.

O3.3-117 – Geospatial Automated Imagery Analysis Tool (GAIA): Incorporating Time Series Satellite Data to Detect Changing Site Conditions

Author: Elizabeth Miller[1]
Co-authors: Anita Lavadie-Bulnes[1]; Emily Schultz-Fellenz[1]; Aviva Sussman[2]; Leo Bynum[2]; Theodore Bowyer[3]
[1]*Los Alamos National Laboratory (LANL), Los Alamos, NM, USA*
[2]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
[3]*Pacific Northwest National Laboratory (PNNL), Richland, USA*
Corresponding Author: millerl@lanl.gov

In order to reduce uncertainties and improve confidence in analyses of potentially anomalous events, accurate event locations are required. However, event location/relocation and replicability can be difficult due to a number of factors, e.g., variability in seismic data processing and spatially sparse network coverage. By leveraging commercially available, high-fidelity satellite data as a supporting data stream, time-separated images could (1) build confidence in seismic data analyses and (2) identify specific areas where change has occurred, such as building construction/demolition or road/facilities improvements. We summarize a novel geospatial processing tool – GAIA: Geospatial Automated Imagery Analysis – that automates image orthorectification and change detection of time-separated images. GAIA is an easy-to-use, ArcGIS-based toolbox with a standardized workflow for image analyses and change detection that significantly reduces geospatial processing time (from hours to <5 minutes). We present the GAIA functionality through relevant exemplar cases with a focus on underground explosions at the Nevada National Security Site (U.S.A.). The use of GAIA in monitoring and verification applications could support event analyses through effective and consistent use of commercially-available satellite imagery. GAIA shows promise for identifying locations of anomalous change and reducing uncertainty in event locations.

Promotional text: This proposed SnT 2021 presentation is aligned with T3.5 Data Analysis Algorithms and will demonstrate an easy-to-deploy monitoring and verification technique that augments event analyses through effective use of commercially-available satellite imagery.

O3.3-153 – Unattended Ground Sensing and In Situ Processing of Geophysical Data

Authors: William O'Rourke[1]; Tyler Morrow[1]; Leon Ross[1]; Matthew DeKoning[1]; Anirudh Patel[1]
[1]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
Corresponding Author: wtorour@sandia.gov

Seismic monitoring systems are typically emplaced along with a complementary infrastructure for power and data exfiltration. In some instances, it may be desirable to deploy a system in a location where it is not feasible or reasonable to provide such infrastructure. In this case there are numerous commercial options that can provide continuous recording and indefinite operation using solar power. However, these locations must still be visited on occasion to retrieve data. We have developed a system that allows for both continuous monitoring and deployment of semi-complex algorithms. Satellite and cellular communications provide both the ability to retrieve data and command/control of the sensor platform. This platform provides for the ability to deploy complex detection and/or classification algorithms to reduce the need to send back continuous data. A system has been deployed at the Redmond Salt Mine in southwestern Utah, USA since October of 2018. A 1-D convolutional neural network (CNN) inference model has been implemented on the unit as an exemplar to demonstrate the ability to classify seismic signals from explosive blasting at the salt mine. The CNN was trained on a dataset labeled by mine level and achieved a F1 Score of 0.802 with the testing set.

O3.3-295 – Commercial UAV Based Magnetic Field Mapping Solution to OSI

Author: Peng Li[1]
Co-authors: Xinlei Xu[1]; Peng Xu[2]; Xinmin He[1]; Xue Hang[1]
[1]*Hope Investment Development Corp. Ltd., Beijing, China*
[2]*Hopong Technology (Guangdong) Co., Ltd., China*
Corresponding Author: lipeng1406@163.com

Based on the lessons learned during the past training and exercise experiences, especially IFE08 and IFE14, inspection efficiency and health & safety concerns are very important factors for conducting ground or airborne magnetic field mapping. This work would propose an UAV based magnetic mapping system, which is also the active result of joint efforts made by experts of OSI and commercial magnetic mapping application. The system is composed mainly of UAV, magnetic mapping sensor arrays as payload, ground based station subsystems. UAV platform is specially designed to minimize its own magnetic field to reduce the interference to the magnetic detection to the minimum. Quantum magnetic detector has been utilized to achieve the sensitive detection of magnetic field over 100 times more accurate than ordinary magnetic detector. Ground based station would achieve UAV flight-control and real-time magnetic mapping data visualization and analysis. The whole UAV based magnetic field mapping system would achieve mapping of 20000 m^2 inspection area per hour with the flight speed of 4 m/s and detection width of 2 meter. Detection of metal anomalies with sensitivity ranging from 0.5 nT to 10 nT could be conducted with the detection depth from 3 meter to 60 meter.
Promotional text: This work would propose an UAV based magnetic field mapping system, which is more safe for inspection team, and more efficient for OSI operation.

P3.3 Remote Sensing, Imagery and Data Acquisition Platforms
Abstracts of Poster Presentations

P3.3-023 – Extending the Infrasonic Array from the Stratosphere with Multimember Ensemble, Long Duration, High Altitude Balloon Constellation

Author: Nick Craine[1]
[1]*Stratodynamics Inc., ON, Canada*
Corresponding Author: ncraine@stratodynamics.ca

Stratodynamics proposes to deploy its NASA designed infrasound sensor aboard a constellation of long duration, high altitude balloons in collaboration with Project Loon. By leveraging Project Loon's distributed data centre computation and blended Analogue Ensemble (AnEn) machine learning techniques, a balloon deployed infrasound sensor could enable revolutionary observations from around the world in real time. The constellation could extend coverage of nuclear blast detection across the ocean and benefit from atmospheric attenuation/amplification effects of a stratospheric flight envelope. Furthermore, sensor calibration could occur from a centralized recovery location with the infrasound instrument suite returned to the ground station on an automated trajectory. This would optimize resources for in-field calibration. A secondary goal of the collaboration leverages these integrated technologies for early detection of Tsunami and earthquake events.

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

P3.3-059 – Commercial Nano Satellite Constellation's Application to Multilateral Arms Control Verification

Author: Peng Li[1]
Co-authors: Hongyu Chen[2]; Liang Chang[2]; Chunpeng Li[2]; Xinmin He[1]; Jing Yang[1]
[1]*Hope Investment Development Corp. Ltd., Beijing, China*
[2]*Micro Satellite Innovation Academy, CAS, Shanghai, China*
Corresponding Author: lipeng1406@163.com

Multilateral arms control and disarmament treaties would require, instead of National Technical Means (NTM), International Technical Means (ITM) as verification solution, due to its efficiency and transparency characteristics. With the rapid development of commercial space technology, space based remote sensing and communication technologies are no longer dominated only by a few states or organizations, consequently, they could be utilized by future multilateral arms control and disarmament regime as verification option, like CTBT. Nano satellite constellation, as a new trend of space technology, has raised attention for modular design, easy production, rapid deployment and cost efficiency. This work would explore Nano satellites' potential application to verification infrastructure. A Nano satellite would cost around several million dollars depending on different payload configurations. A constellation of Nano satellites could be produced and launched within a short period of time. A constellation of Nano remote sensing satellites (resolution up to sub-meter level) would achieve continuous monitoring over a certain inspection area. A constellation of Nano communication satellites would achieve in-real-time communication among inspectors in inspection area or providing communication link for IMS stations, which would provide practical support to the mission like OSI and IMS of CTBT in a place of nowhere.
Promotional text: This work would envisage the potential application of commercial Nano satellite constellation to multilateral arms control and disarmament treaties' verification. This would suggest a practical solution to future space based international verification technology.

P3.3-073 – Study of Ionospheric Total Electron Content (TEC) Variations Before the 6.9 Magnitude Sunda Strait Earthquake in Indonesia in 2019

Author: Ali Azimi[1]
[1]*Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), Jakarta, Indonesia*
Corresponding Author: aliazimiofficial@gmail.com

Researchers around the globe have been carrying out studies related to short-term earthquake predictions. The studies use various approaches of observation methods to find the early signs of anomalies, both physically or chemically changes before the occurrence of earthquakes, as known as precursors. One of the precursors is the emergence of total electron content (TEC) anomaly within the ionosphere. Stress accumulation in the lithosphere can cause microfractures resulting in charged particles possibly release from those microfractures around the earthquake preparation zone toward the atmosphere and disturb the TEC variations. Therefore, this research aims to find the anomaly of TEC before M 6.9 of the 2019 Sunda Strait earthquake which hit several provinces in Indonesia around the Sunda Strait that caused 6 casualties and hundreds of injured. Moreover, this study implements the correlation technique with a threshold and obtains the TEC data from Global Ionospheric Maps (GIM) of the Center for Orbit Determination in Europe (CODE). As a result, it shows that an anomaly of TEC was recorded 22 days before the earthquake occurrence. Also, the Disturbance storm time (Dst) index is utilized to validate that the recorded anomaly is not caused by the geomagnetic storm.
Promotional text: I am very enthusiastic to participate in the CTBT Science and Technology 2021 Conference for improving my capacities and capabilities as a geophysicist. In addition, I also want to expand my network with other researchers, scientists, and professional careers around the globe.

P3.3-110 – Commercial Cost-Efficiency UAV for OSI Trainings and Exercises

Author: Peng Li[1]
Co-authors: Chuande Zhi[2]; Xinmin He[1]; Xue Hang[1]; Yang Xu[1]
[1]*Hope Investment Development Corp. Ltd., Beijing, China*
[2]*Hwa Create Technology Co. Ltd., Beijing, China*
Corresponding Author: lipeng1406@163.com

In CTBT treaty and OSI Operation Manual, Initial Overflight and Additional Overflight would be arranged to provide IT opportunities to understand the overall situation of Inspection Area and conduct specific inspections such as visual observation and multispectral imaging. In the past exercises and training, manned helicopters have been used for a long period of time. With the development of unmanned aerial vehicles (UAV), and also the practical health and safety concerns for inspectors to be onboard the manned airplanes or helicopters in real OSI, the potential application of UAV to OSI trainings and exercises has its practical meaning. This work would propose a commercial cost efficiency unmanned helicopter system, which could be designed to meet the requirements of OSI. The UAV flight height could be restricted within the scope of 1000 meters, the flight boundary could also be restricted within the inspection area taking into consideration of the managed access requirement proposed by the ISP. The flight routes, through programing the flight control software of the UAV, could be jointly worked out by the IT/ISP field teams every day to keep the balance of inspection sufficiency and intrusiveness. The UAV could carry both commercial optical or multispectral payloads.
Promotional text: This work carried out a study on commercial cost-efficiency UAV for OSI, which would provide an option for OSI training and exercises, taking into consideration of health and safety concerns and also the balance keeping for mission efficiency and intrusiveness.

P3.3-112 – Remote Sensing Monitoring of Earthquakes in Sudan with Land Surface Temperature

Author: Hanan Mohammed Elawad Elhassan[1]
[1]*Sensing and Seismology Authority, National Center for Research, Khartoum, Sudan*
Corresponding Author: nonamoh31@yahoo.com

Remote sensing plays a critical role in seismotectonics monitoring of active fault systems. In quest of finding the main geophysical parameters to be surveyed by geospatial and in situ measurements in an integrated monitoring system, this study is focused on the analysis of some earthquake activities recorded in the study area. Specific precursors can be reliably detected using satellite sensors through the capability of thermal remote sensing in the identification of seismically active areas. The behaviour of Land Surface Temperature (LST) is characterized by changes before earthquakes. The objective of this study is to find the relationship between earthquake active areas and thermal properties of earth surface. To this end, LST of MODIS sensor on Terra platform and Sentinel 3 images and some earthquake events from USGS and SRI Catalogues have been used as the material of the study. The study has found that the areas characterized by higher LST for long period have more seismic activity most probably represent major faults.

P3.3-132 – Deformation Identification Using DInSAR Multi-Temporal Analysis and Gravity Method in Supporting Infrastructure Development

Author: Aprilia Puspita[1]
Co-authors: Agustya Martha[1]; Sukendra Martha[2]; Yosef Prihanto[3]
[1]*Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), Jakarta, Indonesia*
[2]*Indonesian Defence University, Jakarta, Indonesia*
[3]*Center of Research, Promotion and Cooperation Geospatial Information Agency (BIG), Jakarta, Indonesia*
Corresponding Author: aprilpuspita86@gmail.com

The lack of information regarding land structures that are prone to deformation can have an impact on the failure of infrastructure development in the New Capital City Region. Therefore, it is necessary to conduct a study on the deformation that occurred in the area, as initial information in determining the location for safer infrastructure development based of the soil structure. This study uses the DinSAR (Differential Interferometry Synthetic Aperture Radar) method which will be analyzed multi-temporally, and combined with the gravity method to estimate the value of Simple Bouguer Anomaly (SBA) to determine the subsurface structure in the study area. The data used are SAR image of Sentinel 1A type SLC C band for the period 2015-2019 and the gravity anomaly model data Free Air Anomaly (FAA). The results obtained indicate that deformation has been identified in several areas with the maximum decrease is 12.97 cm and the maximum increase is 10.01 cm. Areas identified with land subsidence generally have relatively lower SBA values and thus have weaker soil structures. Areas that experience uplifting generally have a relatively higher SBA value than the surrounding area, and can also become areas for deposition of sedimentary material deposits.

Promotional text: I conducted research to map areas that are prone to deformation in the Indonesian New Capital City. By using the DinSAR remote sensing method and the gravity method.

P3.3-488 – Detecting Nuclear Activities Using Geospatial Systems Platforms

Author: Okhala Muacanhia[1]
[1]*National Institute of Mines, Mozambique*
Corresponding Author: muacokhala@yahoo.com.br

Nuclear activity is a significant threat to the world peace. Monitoring such activities is important but in many cases it cannot be done in real time. Remote sensing and geospatial analysis play an important role in detecting the signatures resulting from these activities. These events leave impressive or disguised deep or superficial signatures on the environment, such as changes in the water table or in the surface water. Changes in the surface water can be monitored using data from multispectral imaging platforms. Image processing of non-homogeneity data, for instance, may result in errors caused by noise coming from surface signals and the error introduced by atmospheric effects can results in incorrect interpretation. Detecting water changes in satellite imagery is not an easy process because it depends on the human ability to accurately delineate water bodies. It can be achieved by digitizing manually or by extracting features automatically using a number of computational algorithms. Automatic feature extraction can produce faster results but it may mislead the interpretation because some features may occur naturally and not as the result of nuclear activity. Although image processing can provide some accurate results, it needs to be validated using other techniques to detect nuclear signatures.

Promotional text: It aims to discern how RS can contribute to the monitoring nuclear activity. Understand how effective and efficient some techniques perform is crucial for the response process. The quality of the data and the equipment available are important to assess and monitor such events.

P3.3-586 – Change Detection in Satellite Image Using the Pixel Subtraction Method for Event Verification

Author: Prince Larbi Akor[1]
[1]*Ghana Atomic Energy Commission (GAEC), Accra, Ghana*
Corresponding Author: krlarbi4@gmail.com

Remote sensing satellite data provide opportunity to obtain information about the surface of the earth at different spatial and spectral resolution. Satellite imagery has been used since the 1960s for reconnaissance studies and has since had large number of applications including, disaster mitigation planning, agricultural development, resource monitoring and surveillance purposes. A large number of change detection techniques has been developed to utilize satellite images and while there's no general recommendation on the choice of change detection method, new methods and technologies keep emerging. A satellite image does not only show the graphical presentation but also the quantitative description of the pixels obtained from the value of the reflected solar radiation from the surface. This paper is prepared to show the advantages and the promising use of satellite imagery for the detection of new activities using the pixel subtraction method in change detection technique.

Promotional text: This technology could be vital in remotely obtaining information about clandestine activities.

P3.3-692 – Use of Remote Sensing Technologies for Strengthening Verification Regime

Author: Syed Muhammad Ayub Shah[1]
[1]*National University of Sciences and Technology, Islamabad, Pakistan*
Corresponding Author: agha_ayub@yahoo.com

Micro satellites are cost effective, environmentally friendly and enjoy extended operational life in space. These can be equipped with smart state of the art remote sensors for acquisition of optical, environmental and other data with all the possibilities of detecting related impacts remotely. Success primarily depending upon resolution and other related factors. These acquired data sets can be used to determine surface and subsurface tectonic and other manmade activities to include nuclear detonations. Subsurface activities both deep and shallow leave definite signatures on the surface conditions though depending upon time and other conditions. Speed of S-Wave travelling across the crust depends on the shear modulus and the density expressed by relation B= √(u/p). Therefore a correlation of data acquired from ground stations revealing direction and magnitude with intensity obtained from observations can be correlated with the spontaneous and long terms change detections by the remote sensing platforms. This correlation can yield more authentic scientific evidence towards establishing anthropogenic nuclear activity or detonations in particular. Deep detonations however may take more time and closer observations beside higher resolution of sensors present on board. Launching of a constellation to cover possible end points of body wave impact zones can yield useful results.

Promotional text: Use of Remote Sensing Techologies can be cost effective, more sustainable and more authentic beside being an additional source of data acquisition.

T3.5 Data Analysis Algorithms

Highlights

Seismological, Hydroacoustic and Infrasound (SHI) Data Analysis

Analysis Methods and Tools

P3.5-355 presented Spot Check, a tool based on WCC that can be used in both automatic and interactive mode. In interactive mode, Spot Check can be used for independent review and in-depth analysis of historical as well as real time events and for expert technical analysis. Continuous comparison of the event hypotheses with historical events helps to improve the completeness of the REB. More than 600,000 REB events have been converted into master events with waveform templates at IMS seismic and infrasound stations. The WCC method is used to assess the similarity between event hypotheses and master events on a station by station basis. P3.5-354 studied WCC in the context of large aftershock sequences that follow shallow events with Mw >8. WCC is well suited to the nature of aftershock sequences, i.e. similar repeating events within a confined area. To analyse the possibility to reduce the workload of analysts, the REB, the SEL3 bulletin that is produced by NET-VISA (VSEL3), and the cross-correlation event list (XSEL) were compared using several criteria, such as hit rate, false alarm rate, location and depth error and time residuals. In general, XSEL is closer to the REB than SEL3, which suggests less analyst workload in terms of event creation, confirmation and rejection. Using the best SEL3 events as master events (templates) is almost as efficient as using REB master events.

P3.5-183 attempted to improve the effectiveness of WCC detections using template event metadata and network analysis of corroborating stations. Effective WCC requires templates with broad frequency content to produce reliable single-station detections. However, high frequency information attenuates strongly over distance, limiting such high quality templates to local or near regional distances. A network focused perspective of recurring events improves the credibility of detections, as the number of stations that detected the template event originally, in combination with the relative amplitude of recurring detections, enables the estimation of how many stations are likely to detect the subsequent event. Corroborating detections are added to the detection list automatically, thereby reducing analyst workload.

The NDC in a box software package is developed, distributed and supported by the PTS. It provides NDCs the capability to perform a variety of functions, including receiving, archiving, processing and analysing data from IMS stations. P3.5-392 presented an alternative to configure non-IMS stations, namely a MATLAB tool that processes station parameters, including q calculation of instrument response parameters, and exports them into a database. Standard data files of non-IMS seismic stations can be accessed by NDC in a box via the shared folder of virtual machines, which simplifies the management of parameters for non-IMS seismic stations and data exchange.

P3.5-584 demonstrated how the NDC of the United States has integrated the Generalized-F Detector (Gen-F) into its existing Detection and Features eXtraction (DFX) detection framework, which is very similar to the IDC DFX detection framework. Gen-F uses prior signal and noise information to more reliably detect phases using small and medium aperture arrays. It can be directly integrated into the IDC pipeline as a module that is fully compatible with the input and output of the existing DFX framework as well as the subsequent downstream station and network processing (i.e. StaPro, Global Associator, NET-VISA).

P3.5-453 presented the Coda Calibration Tool, a fast, platform independent, open source coda envelope calibration and processing tool. It was used to estimate the moment magnitude (Mw) on data of varied distances (local to far regional) and a variety of tectonic settings. The estimated Mw was validated by comparing its values and spectra with those estimated using more traditional methods. The tool is freely available (https://github.com/LLNL/coda-calibration-tool). Once a region is calibrated, the tool can be used in routine processing to obtain stable source spectra and associated source information (e.g. Mw, radiated seismic energy, apparent stress, corner frequency, source discrimination on event type and/or depth).

P3.5-561 compared two earthquake detection methods that can handle large quantities of continuous data, namely the matched filter and fingerprinting methods. Their performance was studied using regular seismic activity and aftershocks of a Mw 8.2 event in Mexico as well as seismic activity caused by ice cracking in the Arctic. While the matched filter was easy to implement and precise, the fingerprinting method (essentially comparing the time–frequency signature of signals) was much more efficient computationally.

O3.5-119 proposed a way to make consistent comparisons of seismic location accuracy for 2-D and 3-D velocity models that have been developed using different inversion parameters and ray tracing algorithms. Using open source software (GeoTess Builder, PCalc, LocOO3D) to generate station and phase specific travel time and uncertainty lookup surfaces using the pertinent ray tracing algorithm was suggested. Results showed that although using lookup tables is much faster than ray tracing, the accuracy does not seem to be affected.

O3.5-398 used cross-correlation to detect Lg waves in a seismically active region to find and locate new seismic events with the help of a sparse temporary seismic network in Mongolia and a dense regional network in Kyrgyzstan. About 33,000 events were detected within a period of 5 years with very small 95 per cent confidence ellipses and time residuals. Numerous spatio-temporal event clusters were found and attributed to mining activity.

O3.5-462 argued for the exploitation of all three components of fully 3-C seismic arrays, such as PS28 (Norway) and AS72 (Norway), to take advantage of the coherency of the horizontal components. For S phases, this has the potential to significantly improve detection and characterization. Using the reviewed bulletin of NORSAR, single station event location using the three components increased detections by 50 per cent and resulted in higher signal to noise ratios for both P and S waves. The PMCC algorithm was used to initially process each component, merging the results to form a multicomponent phase detection. In a more computationally intensive technique, all three components were used to rotate the data into a ray coordinate system for a predefined set of azimuth and slowness values. Each component of the rotated data was then processed.

P3.5-198 tested whether detections of small, repeating local events (e.g. mines) can be identified and screened prior to the IDC association process. Detection screening may reduce analyst burden by decreasing the number of false events that are formed by the IDC automatic system. A dynamic correlation processor (DCP) was used to form groups of similar waveforms. Screening was tested at IMS seismic array PS28 (Norway) in the Arctic by applying the IDC beam recipe to the incoming data stream, then using the DCP software to group events. Preliminary results showed that for two beams, 80 per cent and 74 per cent of automated detections were found by the DCP and could be screened before IDC preprocessing.

P3.5-114 presented an automatic and computationally efficient method to pick first arrival points of signals. The method is based on the fractal dimension of seismic traces. The fractal dimension is calculated using the divider method for each sample of the waveform in a window around the arrival (the jumping section), and the arrival is determined. The method was tested on signals with different levels of noise and showed consistent results.

Data fusion is an approach that seeks to integrate disparate sources of data into a unified and comprehensive event analysis. Several approaches (e.g. cost function analysis, Bayesian inference) have demonstrated the power and benefit of data fusion approaches for Treaty verification. Uncertainty characterization is crucial in data fusion processes that combine evidence from multiple sources. P3.5-476 claimed that when pieces of evidence are inconsistent, applying Dempster-Schafer theory reconciles the inconsistencies and improves the inference process. P3.5-127 presented an extension of Fischer's method that fuses statistics from multiphysics waveforms in order to detect small, above ground explosions. In particular, radio, acoustic and seismic waveforms were fused, and the predicted and empirical performance curves were used to estimate the probability and uncertainty of an explosion. The method was applied to near ground solid charge explosions and was shown to reduce detection thresholds, decrease the false alarm rate and improve explosion detection predictive capability.

In P3.5-386, higher-order statistics were used to improve the signal to noise ratio of single sensor waveforms and the variance of the trace to estimate the arrival time of a signal. This method was applied on a variety of signals such as firing bullets or artillery projectiles, mining blasts and other explosions.

Seismic event depth is used for event characterization and location. It is estimated using the time interval between a direct P seismic phase and an echo reflected from the surface, i.e. the pP depth phase. The objective of P3.5-194 was to design and test a semi-automatic depth estimation set of algorithms, with the ultimate goal of building an automatic cepstral analysis tool to be applied on events with depths less than 3 km. The method was tested on seismic waveforms from a series of well-located Nevada Test Site explosions.

P3.5-511 considered an alternative proposal to estimate body wave magnitude, taking into account noise magnitudes. An optimization algorithm was used to estimate the station specific parameters that link observed seismic signals to event magnitude, taking account of noise magnitudes, as well as computing the event magnitudes themselves. The procedure was applied to a large database of IDC events and to primary stations, and the findings strongly support the general, but station specific, linear relationship to compute body wave magnitude from the amplitude to period ratio.

Radionuclide Data Analysis

Event Classification

P3.5-245 described the development of a novel tool for the analysis of radionuclide detection events in the IMS data. An automated process for the fusion of radionuclide and ATM data streams was produced, as well as interactive virtual maps for rapid data interrogation. A specially dedicated, automated analysis pipeline periodically identified plumes of ^{133}Xe and high priority radionuclide detection events, and these were compared with simulated contributions from possible radionuclide emitters.

P3.5-026 described a classification method of particulate radionuclide spectra into "likely normal" (Categories 1 and 2) and "requires scrutiny" (Categories 3, 4, 5) that is entirely ignorant of radionuclide science. Accuracy of over 94 per cent was achieved. It is likely that introducing elements of radionuclide science into the method will further improve the results. P3.5-282 proposed a quality scale that algorithmically assesses measurement reliability by examining measurement metadata and spectrum values to generate a reliability index for each measurement. Individual measurements are weighted such that higher reliability measurements have more influence on the final event. It is anticipated that this work will help prioritize samples for analyst review and shorten the time needed to review samples. When used to complement the radioxenon categorization scheme, this algorithm reduced the number of samples brought to analyst attention by 12 per cent. P3.5-345 described a system for analysing radionuclide monitoring data (ARMD) that realizes the functions of automatic acquisition, database storage, automatic processing, interactive analysis and statistical query of IMS radionuclide data. A comprehensive assessment that was carried out showed the capability of detection and quantitative analysis of weak peaks on top of a high ambient background baseline.

P3.5-610 suggested possible scientific projects to further develop the methods for associating multiple samples to the same radionuclide release event and for backtracking to known sources. These include methods for associating multiple samples to the same release event, providing higher source location estimates, developing the screening flag "ATM backtracking to known sources", correcting ATM in case of systematic discrepancies due to complex terrain, land sea breeze and mountains, as well as the use of isotopic ratio measurements for screening. The data required to validate the results of these projects were described.

Background and Noise

Xenon background levels impose limitations on the size of radionuclide anomalous signals that can be discerned. O3.5-343 calculated maps and statistical estimators of network capability for xenon background levels, using a threshold balanced between the system minimum detectable concentration (MDC) and background intensity and variability. For most of the earth, using MDC values is reasonable. However, for a number of locations, background xenon concentrations are frequently larger than the measurement equipment limitations.
Release of activation-generated radioxenon can occasionally be observed at noble gas systems of the IMS. Sources of activation may release products that interfere with beta–gamma spectroscopy analysis of radioxenon. The literature appears to show conflicting results for the isotopic ratios from neutron activation of stable xenon in the releases from nuclear research reactors. O3.5-456 used ORIGEN simulations to investigate various scenarios of generating radioxenon from activation to test the hypothesis that the isotopic activity ratios can be used as a discriminator for activation or fission.

P3.5-235 described a method to calculate the activity of radon in nuclear detectors using the coincidence beta–gamma spectrum. The impact on the MDC of radioxenon and its uncertainties can be determined, as well as the radon rejection levels needed to maintain optimal radioxenon detection sensitivity.

P3.5-483 presented a method for assessing ^{37}Ar emissions. Argon-37 is an important indicator of an underground nuclear explosion, but normal operational releases from nuclear facilities contribute to its atmospheric background. It can be produced via neutron activation of air or of gas dissolved in water. A two step method was suggested for assessing ^{37}Ar releases from nuclear research reactors. First, simulations with ORIGEN determine isotopic ratios of ^{37}Ar and an appropriate proxy, such as ^{41}Ar, for which stack release data are available. Then the retention time is used to account for the time before the release through the stack.

Analysis Methods and Software

P3.5-507 provided an overview of radionuclide analysis procedures at the IDC. It reviewed the three sets of approaches that are currently used: the single channel analyser curve for particulate, the least squares regression on gamma and X ray peaks of xenon isotopes for high resolution spectra, and the net count calculation method for beta–gamma coincidence spectra for noble gas. The discussion raised the question of the potential for further enhancing IDC spectrum analysis methods of CTBT radionuclide measurements after 25 years of progressive development. A summary of this presentation can be found in the 25th anniversary section of this report.

O3.5-573 updated the status of and discussed future plans for four ongoing IDC radionuclide software applications (1) iNtegrated Software Platform for Interactive Radionuclide rEview (iNSPIRE), (2) automatic Software Tool for RAdionuclide Data Analysis (autoSTRADA), (3) Geant4 based RAdioNuclide Detector Simulation (GRANDSim) and (4) a new web based application (RNToolkit).

P3.5-407 described the Forensic Radionuclide Event Analysis and Reconstruction Tool (FREAR). The new tool applies Bayesian statistical inference methods to reconstruct the emission source by fusion of radionuclide data and ATM. Trials on real world reconstructions have demonstrated clear and dramatic improvements over standard correlation techniques, such as the PSR algorithm. To further test the tool, two blind tests were conducted with synthetic source terms with short and long range transport.

During the testing of the Xenon International system, a large activity ^{133}Xe spike caused false positive hits for ^{133m}Xe and ^{113m}Xe, with similar false positive hits expected when the metastable isotopes are present. P3.5-278 described the development of algorithms that include interference terms for the four radioxenon isotopes and the radon daughters to reduce biasing and false positives that are caused by large interference radioxenon spikes. The algorithms use matrix inversion to solve the correlated interference terms simultaneously. The additional interference terms provide radioxenon analysis that is more accurate under more conditions and reduces the number of false positive results.

The evolution of the SPALAX systems, now equipped with high resolution beta–gamma detection equipment (PIPSBox/HPGe), led to the development of dedicated spectrum analysis algorithms. P3.5-300 presented a computer based study to evaluate these algorithms. Monte Carlo simulations produced statistical distributions and permitted the proper evaluation of associated uncertainties and detection limits. The discrepancies between algorithms and detector configurations were presented.

P3.5-442 presented a new algorithm for processing beta–gamma coincidence spectra based on the maximum likelihood and non-negative least squares (NNLS) methods. The algorithm allows simultaneous processing of the signal in all regions of interest (ROIs). This approach has a number of advantages over the net count calculation algorithm and provides a solution to the problem of processing beta–gamma spectra in the most general form. A program was developed for processing beta–gamma spectra using a new algorithm, and the activities of xenon were calculated using the data obtained by the MIKS system in 2020.

In the net count calculation method, detected decay events are plotted on a beta–gamma coincidence histogram and events are tallied inside ROIs specific to a given radioxenon isotope. P3.5-236 discussed a possible technique to mitigate effects of detector gain drifts through the use of a larger ROI in the isotopic analysis. Improving the sensitivity for radioxenon beta–gamma measurements by optimizing the ROI limits for each sample was suggested in P3.5-377. Such optimization decreased the minimum detectable activity (MDA) for some detectors by up to 50 per cent.

P3.5-508 described the use of Monte Carlo calculations of isotopic ratios of fission products, with the aim of trying to assess the time of explosion events under assumed scenarios. The Monte Carlo simulations produce probability distributions of isotopic ratios based on input distributions related to spectrum measurements and decay chains. The isotopic ratios, associated uncertainty and limits of the coverage interval can be estimated accordingly.

P3.5-550 reported on the development of a toolkit for parametric study of IMS radionuclide concentration data. Several types of graphics have been produced for in-depth analysis and visualization of data that go beyond the capabilities of the presently used CRTool.

Calibration and Quality Control

P3.5-250 discussed tools for automatic quality checks of calibration files for radionuclide particulate stations. A ROOT based software program has been developed to automatically process spectra and compare them against requirements. Discrepancies are flagged for correction, resulting in a swift assessment of the calibration. P3.5-234 examined quality control measurements that are taken to monitor and correct for gain drifts in radioxenon nuclear detectors. The measurement is performed by examining the 662 keV photoelectric peak of a ^{137}Cs source. Much information can be obtained from the collected spectra and utilized to monitor the health and performance of the nuclear detectors over time by determining the relative efficiency, resolution and gains with respect to the check source.

Typical gain monitoring and correction of radioxenon system measurements is done using a mixed ^{137}Cs/^{154}Eu source. While several gamma ray lines can be used for gain adjustments, the beta detector does not produce clear peaks. P3.5-280 described a method that uses the 2-D Compton scatter line and rotates the frame of reference until the projection of the Compton scatter line forms a peak. This method optimizes the use of counting statistics available from the Compton scatter line and gives reliable results, even with relatively short measurement times.

O3.5 Data Analysis Algorithms
Abstracts of Oral Presentations

O3.5-119 – Comparing Three Dimensional Velocity Models for Seismic Location Accuracy Using a Consistent Travel Time Framework

Author: Michael L. Begnaud[1]
Co-authors: Sanford Ballard[2]; Christopher Young[2]; Andrea Conley[2]; Patrick Hammond[2]
[1]*Los Alamos National Laboratory (LANL), Los Alamos, NM, USA*
[2]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
Corresponding Author: mbegnaud@lanl.gov

Location algorithms have relied on simple, one-dimensional (1D) velocity models for fast, seismic event locations. The fast-computational speed of these models made them the preferred type of velocity model for operational needs. Higher-dimensional (2D-3D) seismic velocity models are becoming readily available and provide more accurate event locations over 1D models. The computational requirements of these 2D-3D models tend to make their operational use prohibitive. 1D are generally used as travel-time lookup tables, one for each seismic phase, with travel-times pre-calculated for event distance and depth, that are fast to use. Comparing location accuracy for 2D-3D seismic velocity models tends to be problematic as each model is determined using different ray-tracing algorithms. Attempting to use a different algorithm than used to develop a model usually results in poor travel-time prediction. We will demonstrate the current/updated ability to quickly create travel-time correction surfaces using an open-source framework (PCalc+GeoTess, www.sandia.gov/geotess) that easily stores 3D travel-time data. This framework overcomes the raytracing algorithm hurdle because the lookup tables can be generated using the exact ray-tracing algorithm that is preferred for the model. Having a common travel-time framework for a location algorithm allows individual velocity models to be compared in a fair, consistent manner.

Promotional text: Allowing for direct comparison and/or use of 3D velocity models pertains to Goal 1 for identifying opportunities/methods for improving nuclear test monitoring. Goals 4-5 are also relevant for supporting the exchange of knowledge and promoting wider application of techniques.

O3.5-343 – Impact of Environmental Backgrounds on Atmospheric Monitoring of Nuclear Explosions: Selected Results

Authors: Harry Miley[1]; Paul Eslinger[1]
Co-authors: Christine Johnson[1]; Ramesh Sarathi[1]; Steven Rosenthal[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Authors: harry.miley@pnnl.gov, paul.eslinger@pnnl.gov

The International Monitoring System (IMS) was designed based on planned sensitivity estimates, such as radionuclide (RN) system minimum detectable concentration (MDC), but without knowledge of background levels. Recent background simulations and atmospheric transport modeling calculations show that for most of the Earth, using MDC values is still reasonable. However, for a number of locations, background xenon concentrations are frequently larger than the measurement equipment limitations and impose mild to severe limitations on the size of anomalous signal that can be discerned. The authors have calculated maps and statistical estimators of network capability for computed xenon background levels, using a threshold balanced between the MDC and background intensity and variability. Despite these limitations, xenon continues to be a very worthwhile monitoring method.
Promotional text: Xenon background is a key issue in the performance of the IMS. Understanding this will guide analysis from existing equipment and inform future deployment of next-generation capability.

O3.5-398 – Regional Waveform Correlation Detection and Location for Seismic Events in and Near Mongolia

Authors: David P. Schaff[1]; Paul G. Richards[1]
[1]*Lamont-Doherty Earth Observatory of Columbia University, New York, NY, USA*
Corresponding Author: dschaff@ldeo.columbia.edu

We have engaged in broad-area regional monitoring for Mongolia and nearby regions, applying cross-correlation to long time windows for Lg-waves. For 2012 to 2016, using 4777 templates from a longer time-period, detections were made on searches of continuous data for a sparse network of IMS array stations, plus six long-running three-component open stations. Many candidate events were detected, for which there were too few stations in the detection network to perform locations. Fortunately a temporary PASSCAL network with many stations had been deployed in the region, which overlapped with the time period of our study. Adding windowed data from that network, based on expected arrival times for Lg-waves, we measured differential travel times to make location estimates. We have obtained pair-wise locations for 35,096 events in the detected catalog (4.7 million pairs of events). Location results are similar to those obtained in a previous study for all of China (Schaff et al, BSSA, June 2018) with average residuals of 0.0164 s; and 95% confidence ellipses with average 157 m semi-major axes. 93% of the pairs are less than 1 km apart. We are computing locations within large clusters of over 1000 events in several areas.
Promotional text: In addition to high-precision methods for locating events in an active seismic region, using continuous data from a sparse network, we have conducted large-scale searches for new seismic events. We have located them too, from open data, with quick searching methods.

O3.5-456 – Radioxenon Isotopic Ratios from Activation of Stable Xenon in Releases from Nuclear Facilities in Relation to Fission Sources Visualized in Multi-Isotope-Ratio Plots

Author: Pouneh Tayyebi[1]
Co-author: Martin B. Kalinowski[2]
[1]*Iran Nuclear Regulatory Authority, Tehran, Iran*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: pooneh.tayyebi@gmail.com

Evidence has shown that besides radioxenon from fission, release of activation-generated radioxenon can occasionally be observed at noble gas systems of the International Monitoring System (IMS). The literature appears to show conflicting results for the isotopic ratios from activation of stable xenon in the releases from nuclear research reactors (NRRs). This study uses ORIGEN simulations to investigate various scenarios of generating radioxenon from activation. Different neutron spectra and activation of air as well as gas dissolved in the water are studied. The main goal is to test the hypothesis that the isotopic activity ratios can be used as a discriminator for activation or fission being the dominating source of radioxenon releases from NRRs or other nuclear facilities. This is important because any source of activated xenon that can be observed in IMS samples may release other activation products as well ^{125}Xe, ^{127}Xe and ^{129m}Xe which interfere with the beta-gamma spectroscopy analysis methods which are applied by the International Data Centre (IDC). This is an important scientific foundation to decide whether interference corrections for these non-traditional radioxenon isotopes need to be introduced to the operational software.
Promotional text: A foundation for estimating the impact that radioxenon generated by neutron activation and released from nuclear facilities can have on IMS samples is presented for deciding whether interference corrections have to be introduced to the operational analysis software.

O3.5-462 – Multicomponent Seismic Arrays: Demonstrating Their Potential for Improved Event Detection and Characterization

Author: Claire Labonne[1]
Co-authors: Charlotte Groult[1]; Ben Dando[2]; Sven Peter Näsholm[2]; Tormod Kværna[2]; Yoann Cano[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[2]*Norwegian Seismic Array (NORSAR), Kjeller, Norway*
Corresponding Author: claire.labonne@cea.fr

IMS seismic arrays are predominantly formed using multiple vertical sensors with a single three-component (3-C) seismometer co-located at one site. The deployment of fully 3-C seismic arrays, such as ARCES (PS28) and SPITS (AS72), offers the possibility to take additional advantage of the coherency on the horizontal components. For the case of S-phases, this has the potential to significantly improve their detection and characterization. Despite this, 3-C arrays are currently poorly exploited in automatic phase detection and classification algorithms. Using events from the 2020 NORSAR regional reviewed bulletin and based on data from the ARCES and SPITS arrays, our work focuses on demonstrating the benefits of using all three components for array processing. We use the PMCC (Progressive Multi-Channel Correlation) algorithm to initially process each individual component, merging the results to form a multi-component phase detection, from which a Kurtosis phase picker is applied. For a second, more computationally intensive technique, we use all three components to rotate our data into a ray-coordinate system for a predefined set of azimuth and slowness values. Each component of the rotated data are then processed, with the resulting detections compared to both the vertical-only results and the PMCC multi-component technique.
Promotional text: We investigate solutions to efficiently use horizontal components for seismic array processing. Our study aims to demonstrate how the IMS 3C-arrays can be better exploited, while also highlighting the advantages of such 3-C deployments for event detection.

O3.5-573 – Novel IDC Software Applications for Radionuclide Data Analysis

Author: Abdelhakim Gheddou[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: abdelhakim.gheddou@ctbto.org

The CTBTO International Data Centre (IDC) initiated the development of novel software applications for modernizing automatic processing and interactive analysis of radionuclide data from the International Monitoring System (IMS). The ongoing projects aim at completing the migration to open source license free software, unifying the processing tools for particulates and noble gas, integrating new technologies and analysis methods as well as enhancing the IDC products and dissemination tools for National Data Centers (NDCs). The presentation will provide updated status and future plans on ongoing projects: (a) iNtegrated Software Platform for Interactive Radionuclide rEview (iNSPIRE), (b) automatic Software Tool for RAdionuclide Data Analysis (autoSTRADA), (c) Geant4 based RAdioNuclide Detector Simulation (GRANDSim) and (d) new web based application (RNToolkit).
Promotional text: The contribution presents an update on novel IDC radionuclide software applications iNSPIRE, autoSTRADA, GRANDSim and RNToolkit.

P3.5 Data Analysis Algorithms
Abstracts of Poster Presentations

P3.5-026 – Automatic Classification of Particulate Radionuclide Spectra

Author: Tryggvi Edwald[1]
[1]*Independent Researcher, Vienna, Austria*
Corresponding Author: tryggvi.edwald@gmail.com

This poster describes progress in 2020 of classifying IMS particulate radionuclide spectra into "likely normal" (Cat. 1,2) and "requires scrutiny" (Cat.3,4,5). The aim is to assist IDC radionuclide analysts by reducing their workload of "normal" spectra, which are the majority of IMS spectra. The method described here is entirely ignorant of radionuclide science. The point of these efforts was to find how close to a correct classification one could get without using any radionuclide science. Accuracy of over 94% has been achieved. It is likely that injecting radionuclide science into the method will improve the results.

P3.5-114 – A New Automatic First Arrival Picking Algorithm Based on a Mathematical Approach with Considering the Fractal Dimension

Author: Shamseddin Esmaeili[1]
Co-authors: Hadi Esmaeili[2]; Ramin Nikrouz[2]
[1]*Razi University of Kermanshah, Kermanshah, Iran*
[2]*Department of Geology, Urmia University, Urmia, Iran*
Corresponding Author: s.esmaeili@razi.ac.ir

This research demonstrates a new accurate automated method for seismic first arrival picking that is based on a mathematical approach with considering the fractal dimension of seismic traces. Reliable and accurate detection of the first arrival is a key step for the determination of seismic parameters. In this work, we introduce an adaptive mathematical triggering algorithm by considering the fractal dimension variations along the seismic

records. The results show that our proposed algorithm is quite reliable and it is less susceptible to false-positive detection errors. This suggests adaptive mathematical fractal dimension algorithm may be less sensitive to analyst parameter choices than other methods. Our proposed algorithm was verified using seismic records and synthesized seismic records with different noise levels. Also, we showed the performance and the results of the mathematical fractal dimension method on seismic records. The results emphasize that our proposed algorithm is quite practical and reliable for noisy and bad seismic records, and as well as, it is computationally efficient and easy to apply.
Promotional text: This research presents a new accurate automated method for seismic first arrival picking that is based on a mathematical approach with considering the fractal dimension of seismic traces. Our proposed method is quite viable and efficient for the determination of first arrivals.

P3.5-127 – Distributed Detection and Fusion of Multi-Signature Explosion-Sourced Waveforms: Predictive Capability, Quantitative Performance and Experimental Demonstration

Authors: Joshua Carmichael[1]; Neill Symons[1]; Brian Williams[1]; Dale Anderson[1]
[1]*Los Alamos National Laboratory (LANL), Los Alamos, NM, USA*
Corresponding Author: joshuac@lanl.gov

Quantitative methods that enable multi-physics waveform fusion support explosion monitoring and general research in geophysical processes that comprises background emissions for explosion monitoring. We offer a constructive method to fuse statistics that we derive from multi-physics waveforms and improve our capability to detect small, above-ground explosions over methods that consume single waveforms. Our method advances Fisher's Method to operate under both hypotheses of a binary test on noisy data and provides density functions required to forecast our ability to screen fused explosion signatures from noise. We apply this method against 12-day, multi-signature chemical explosion and noise records to illustrate three primary results. We show that: (1) a fused multi-physics statistic that combines radio, acoustic, and seismic waveforms can identify explosions roughly 0.8 magnitude units lower than an acoustic emission, STA/LTA detector for the same detection probability; (2) we can quantitively predict how this fused, multi-physics statistic performs with Fisher's Method; and (3) that this data stream method competes well with lower fidelity, decentralized detection approaches. We additionally present our preliminary, but more general work that addresses multi-signature association of data streams to a common source.
Promotional text: This work supports the objective of improving nuclear test monitoring and verification by using chemical explosion test data to develop better methods of signal detection.

P3.5-183 – Using Waveform Correlation and Template Event Metadata to Reduce Analyst Workload

Author: Amy Sundermier[1]
Co-authors: Rigobert Tibi[1]; Christopher Young[1]
[1]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
Corresponding Author: asunder@sandia.gov

Waveform cross correlation uses template waveforms from historical seismic events to detect recurring events from the same seismic source. Waveform cross correlation works well for dense regional networks, so research challenges arise when applying similar techniques to a sparse network such as the International Monitoring System (IMS). Effective waveform cross correlation requires templates with broad frequency content to produce reliable single-station detections over a broad area, but because high-frequency information attenuates strongly over distance, such high-quality templates with broad frequency content only exist for stations at local to near-regional distances from the target seismic sources. Our research seeks to improve the effectiveness of waveform cross correlation detections through use of template event metadata and network analysis of corroborating stations. We seek patterns of multiple station corroboration of seismic arrivals to generate a more effective collection of template waveforms for a network of stations. A network-focused perspective of recurring events improves the credibility of detections, since the number of stations that detected the template event originally, in combination with the relative amplitude of recurring detection, enables estimation of how many stations are likely to detect the subsequent event; thus, we select waveform correlation detections to reduce analyst workload.

Promotional text: Identify opportunities and methods for improving nuclear test monitoring and verification by improving IDC automated pipeline with waveform correlation techniques to reduce analyst effort on routine recurring events such as mining blasts.

P3.5-194 – A Semi-Automatic Cepstral Method for Seismic Event Depth Estimation

Author: Ileana Tibuleac[1]
Co-authors: Daniel Stayt[1]; Robert Kemerait[1]; Marina Capuano[1]
[1]*Air Force Technical Applications Center (AFTAC), FL, USA*
Corresponding Author: ileana.tibuleac@us.af.mil

Seismic event depth is used for event characterization and location and is estimated using the vertical component of the velocity at the source and half the time interval between a direct P seismic phase and a similar shape echo, reflected from the surface, named depth phase or pP. The signal-echo separation can be estimated with cepstral methods designed for shallow-event cases when the P and pP seismic phases are not well-separated. Our cepstral analysis method named CWAM1.0 used homomorphic deconvolution to retrieve the signal and echo, and proposed fifteen metrics to estimate the solution credibility. Because CWAM1.0 involves long and tedious trial-and-error analysis to find the best input analysis window parameters, the objective of this study was to design and test a semi-automatic depth estimation set of algorithms named CAT1.0, with the ultimate goal of building an automatic cepstral analysis tool to be applied on events with depth less than 3 km. The tool is tested in this study on seismic waveforms from a series of well-located Nevada Test Site explosions.

Promotional text: The objective of this study was to design and test a semi-automatic depth estimation set of algorithms, with the ultimate goal of building an automatic cepstral analysis tool to be applied on events with depth less than 3 km.

P3.5-198 – The Application of a Dynamic Correlation Processor for IMS Detection Screening

Author: Ana Aguiar[1]
Co-authors: Douglas Dodge[1]; Stephen Myers[1]
[1]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: aguiarmoya1@llnl.gov

The vast majority of International Monitoring System (IMS) seismic detections are associated with small events that are detected by only one station. Large numbers of small-event detections at each IMS station increases the probability of the International Data Centre (IDC) automatic system building false events. We test whether detections of small, repeating local events (e.g., mines) can be identified and screened prior to the IDC association process. We use a dynamic correlation processor (DCP) (Harris and Dodge, 2011) to form groups of similar waveforms, and we then manually associate these groups to known mines and other sources. We first test screening at the Norwegian Arctic ARCES IMS array by applying the IDC beam recipe to the incoming data steam, then using the DCP software to group events. Preliminary results on this array show that for two beams, 80% and 74% of automated detections are found by DCP and may be screened before IDC preprocessing. These promising results suggest that the DCP screening method may be used to identify and screen detections that are not of interest to monitoring before they are passed to the IDC automatic system. Detection screening may significantly reduce analyst effort to produce the Reviewed Event Bulletin.

Promotional text: Small, repeating events that are detected by one IMS seismic station may be identified and screened prior to the event association process. Detection screening may reduce analyst burden by decreasing the number of false events that are formed by the IDC automatic system.

P3.5-234 – Performance Monitoring of Beta–Gamma Detectors Using Quality Control Data

Authors: Michael Mayer[1]; Matthew Cooper[1]; James Ely[1]; Justin McIntyre[1]; Johnathan Slack[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: michael.mayer@pnnl.gov

Quality Control (QC) measurements are taken to monitor and correct for gain drifts in radioxenon nuclear detectors. The measurement is performed by placing a ^{137}Cs source near the detector and measuring the position of the 662-keV photoelectric peak in the NaI detector and determining the endpoint for the Compton scatter distribution, but there is much more information that can be gleaned from the collected spectra, which PNNL is now leveraging. This QC data set is being utilized to additionally monitor the health and performance of the nuclear detectors over time by determining the relative efficiency, resolutions, and gains with respect to the check source. Baseline determination of these detector characteristics and placement of quality control limits enables an operator to determine if an issue is happening or has happened with the detectors. This presentation will go over how we determine these QC detector characteristics and how they can be used to infer the health of the detectors.

Promotional text: This presentation provides new opportunities and methods for improving nuclear test monitoring and verification by leveraging existing data to monitor the nuclear detectors' health.

P3.5-235 – Method for Calculating Radon Activity and Radon Rejection

Authors: Michael Mayer[1]; Matthew Cooper[1]; James Ely[1]; James Hayes[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: michael.mayer@pnnl.gov

Radioxenon detection systems chemically separate and purify xenon from the collected atmospheric sample. These systems reject radon to a high degree during this processing step. On occasion, radon will make it to the nuclear detectors and its progeny will interfere with the radioxenon measurement. The minimum-detectable-concentration values of an atmospheric monitoring system will also be negatively impacted by the presence of this radon. To minimize these consequences, it is important to understand how much radon made it to the nuclear detectors and its effect. We have developed a way to calculate the activity of radon in the nuclear detectors using the coincidence beta-gamma spectrum and to determine the impact to the minimum-detectable-concentrations. This presentation will discuss the method to calculate the radon rejection levels needed to maintain optimal radioxenon detection sensitivity and the impact of radon on radioxenon uncertainties.

Promotional text: This presentation provides new opportunities and methods for improving nuclear test monitoring and verification by allowing radon activity and rejection levels of a system to be determined.

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

P3.5-236 – Technique to Mitigate Effects of Detector Gain Drifts Through Use of Larger Regions of Interest

Authors: Michael Mayer[1]; Matthew Cooper[1]; James Ely[1]; James Hayes[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: michael.mayer@pnnl.gov

Radioxenon measurements use the net-count method to determine the activity for the radioxenon isotopes of interest. Detected decay events are plotted on a beta-gamma coincidence histogram and events are tallied inside regions-of-interest specific to a given radioxenon isotope. The boundaries of these regions are based on both the resolution of the detector and the physics of the emitted radiation of the radioisotope. Nuclear detector gain drifts can cause the energy calibration of the detector to be incorrect and the decay events to fall outside the region, causing inaccurate activity measurements if the detector gain drifts too much. One possible method to mitigate the effect of gain drifts is to increase the size of the regions-of-interest. This presentation will demonstrate the effect gain shifts have on activity calculations, how larger regions decrease this effect, and the impact larger regions have on the sensitivity of the measurement.

Promotional text: This presentation provides new methods for improving nuclear test monitoring and verification by providing alternative activity measurement analysis techniques.

P3.5-245 – A Data Visualisation Tool for Radionuclide Detection Events

Author: Daniel Chester[1]
Co-authors: Matthew Goodwin[1]; Ashley Davies[1]; Richard Britton[2]
[1]*AWE Aldermaston, Reading, United Kingdom*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: daniel.chester@awe.co.uk

The United Kingdom National Data Centre (UK NDC) has developed a novel tool for the analysis of radionuclide (RN) detection events on the International Monitoring System (IMS). An automated process for the fusion of RN and atmospheric transport modelling (ATM) data streams has been produced which efficiently compiles a wealth of information in a single source and puts interactive virtual maps at an analyst's disposal for rapid data interrogation. A specially dedicated, automated radionuclide analysis pipeline periodically identifies 'plumes' of Xe-133 and high-priority RN detection events at IMS stations and these are compared with simulated station contributions from possible radionuclide emitters. For a given detection event, features such as wind direction vectors, station history and 2D representations of emission contributions are all available for visualization and interaction within the new tool.

Promotional text: This poster outlines recent developments to the United Kingdom NDC radionuclide detection event analysis capabilities. An interactive data visualisation tool allows for the rapid interrogation of potential source locations.

P3.5-250 – Automatic Quality Checks of the Calibration Files for Radionuclide Particulate Stations

Authors: Andreas Wiens[1]; Claus Johannsen[1]; Nicholas Mascarenhas[1]; Halit Tatlisu[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: andreas.wiens@ctbto.org

The International Monitoring System Division (IMS) of the CTBTO aims to maximize the data availability from the radionuclide monitoring systems. The detectors at the radionuclide stations require a calibration whenever a new detector is installed or the geometry is changed. The maintenance unit of the IMS division is responsible for assisting the Station operator during calibration, ensuring that the data quality meets the requirements and that calibration and geometry files are submitted to the PTS in a timely manner. A ROOT based software program has been developed to automatically process the spectrum, compare it against the requirements and to the calibration pairs generated at the station. Discrepancies are then flagged for correction. The process is the following. First the certificate block is retrieved from the calibration (CALIBPHD) file. Then the peaks at the energies from the certificate block are found and fitted. The results from the fits are compared against the requirements and data pairs from the station. The peak fits as well as both efficiency and FWHM curves are plotted and tabulated. The results displayed allow one to assess the calibration spectrum swiftly and as a result to take immediate actions as needed.
Promotional text: A ROOT based software program has been developed to automatically process the spectrum, compare it against the requirements and to the calibration pairs generated at the station. Discrepancies are then flagged for correction resulting in a swift assessment of the calibration.

P3.5-278 – Accounting for Radioxenon Interferences

Authors: Matthew Cooper[1]; Brittany Abromeit[1]; James Ely[1]; Daniel Keller[1]; Michael Mayer[1]; Justin McIntyre[1]; Johnathan Slack[1]; Thomas Suckow[1]; Ryan Wilson[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: matthew.cooper@pnnl.gov

Radioxenon analysis is a critical part of monitoring for underground nuclear explosions. Algorithms that determine the activity concentration of a sample were developed over many years and continue to be updated as lessons are learned from automated radioxenon analysis systems. During Xenon International testing in the U.S., a large activity ^{133}Xe spike caused false positive hits for ^{133m}Xe and ^{131m}Xe, with similar false positive hits are expected when the metastable isotopes are present. The U.S. is developing algorithms that include interference terms for the four radioxenon isotopes and the radon daughters to reduce the biasing and false positives that are caused by large interference radioxenon spikes. The algorithms will use matrix inversion to solve the correlated interference terms simultaneously. The additional interference terms will provide radioxenon analysis that is more accurate under more conditions and will reduce the number of false positive results.
Promotional text: This work discusses a method that will improve nuclear test monitoring and verification by improving the accuracy of radioxenon analysis and is intended to disseminate the concepts to the broader monitoring community.

P3.5-280 – Quality Control Source Analysis Using a Rotating Frame of Reference

Authors: Matthew Cooper[1]; James Ely[1]; Warren Harper[1]; Michael Mayer[1]; Ryan Wilson[1]; Charles Hubbard[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: matthew.cooper@pnnl.gov

Development of methods to track beta-gamma detector gains is important to the accuracy of radioxenon system measurements. Typical gain monitoring and correction is done using a mixed $^{137}Cs/^{154}Eu$ source, which results in several gamma-ray lines that can be fit by Gaussian distributions, and gain adjustments made to bring the peaks into the expected channel. The beta detector on the other hand does not produce clear peaks, so peaks are made by taking slices from the 2-D Compton scatter line and then analyzed. The method developed at PNNL takes a different approach; it uses the 2-D Compton scatter line and rotates the frame of reference until the projection of the Compton scatter line forms a peak. This method optimizes the use of counting statistics available from the Compton scatter and gives reliable results even with relatively short measurement times.

Promotional text: This work discusses a method under development that will improve nuclear test monitoring and verification by improving the accuracy of radioxenon analysis and will disseminate alternative detector gain stability check that performs well even with low counting statistics.

P3.5-282 – Automatic Radioxenon Data Validation for Increased Measurement Reliability

Author: Jennifer Mendez[1]
Co-author: Brian Schrom[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: jennifer.mendez@pnnl.gov

Radionuclide event formation needs reliable detections. Because of the relatively large uncertainty in atmospheric transport modelling, which radionuclide event formation relies on, radionuclide event formation benefits from higher quality measurement analysis, specifically minimizing the number of false positive and false negative detections. This work proposes a quality scale that algorithmically assesses measurement reliability by examining measurement metadata and spectrum values to generate a reliability index for each measurement. Individual measurements used to form an event can be weighted such that lower reliability measurements have less influence on the final event and higher reliability measurements have more influence on the final event. In addition to being useful for automatic event formation screening, it is anticipated that this work will help prioritize samples for analyst review and shorten time needed to review samples. When used to complement the radioxenon Noble Gas Categorization scheme this algorithm reduced the number of samples brought to analyst attention, samples categorized as level C, by 12%.

Promotional text: This project provides an automated method to improve nuclear test monitoring and verification by increasing the reliability of measurements.

P3.5-300 – Recent Algorithm Developments on Methods for the Analysis of Radioxenon Beta–Gamma Coincidence Spectrum

Authors: Antoine Cagniant[1]; Olivier Delaune[1]; Philippe Gross[1]; Sylvain Topin[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: antoine.cagniant@cea.fr

The evolution of the SPALAX systems, now equipped with a high resolution beta/gamma detection equipement (PIPSBox/HPge), led CEA/DAM to develop dedicated spectrum analysis algorithms. The first developments were presented to CTBTO noble gas experts during the "Paris equation" meeting in March 2018. Lately, CEA/DAM conducted a computer-based study to evaluate those algorithms. A large low count rate spectra database was generated by Monte-Carlo simulations for several detector configurations. It permitted the production of counts statistical distributions and the proper evaluation of associated uncertainties, the critical and detection limits. The discrepancies between algorithms and detector configurations will be presented.

P3.5-345 – ARMD: A Suite of Analysis System for CTBT Radionuclide Monitoring Data

Authors: Xinjun Zhang[1]; Shiian Wang[1]; Qi Li[1]; Yanqing Fan[1]; Huaimao Jia[1]; Yungang Zhao[1]; JianFang Shi[1]
[1]*CTBT Beijing National Data Centre and Beijing Radionuclide Laboratory, Beijing, China*
Corresponding Author: xinjun.zhang@nrl.org.cn

The analysis system for CTBT radionuclide monitoring data is developed by the CNNDC. The system realizes the functions of automatic acquisition, database storage, automatic processing, interactive analysis and statistical query of IMS radionuclide monitoring data. A comprehensive assessment is carried out. The results show that the data analysis system has the capability of detection and quantitative analysis of weak peaks on the high ambient background baseline.

Promotional text: ARMD system realizes the functions of automatic acquisition, database storage, automatic processing, interactive analysis and statistical query of IMS radionuclide. ARMD system shows the technical ability of CNNDC in the comprehensive analysis and processing of radionuclide data.

P3.5-354 – Recovery of the Largest Aftershock Sequences Using Waveform Cross-Correlation

Authors: Ivan Kitov[1]; Christos Saragiotis[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: ivan.kitov@ctbto.org

Shallow earthquakes with Mw>8-9 usually create extensive aftershock activity with thousands of events with mb>3.5. This is a tremendous challenge for IDC automatic and interactive processing, with the Tohoku-2011 earthquake being a prime example. The SHI IDC processing is fine-tuned to find the smallest events (with fixed human resources), and thousands of similar events within a very short time stresses the system. The waveform cross-correlation (WCC) method - based on the similarity of neighboring seismic sources and using a fixed station set - is an alternative method well suited to the nature of the aftershock sequences, i.e. similar repeating events within a confined area measured by seismic stations of the International Monitoring System. The IDC has been testing the performance of a prototype WCC-based processing pipeline. There is a feature very specific to the IDC: the resulting cross-correlation bulletin (XSEL) contains only the events matching the full set of event definition criteria applied to the Reviewed Event Bulletin. Here we present the testing results as obtained from four different aftershocks sequences. For these sequences we show the effect of varying defining parameters of the prototype WCC pipeline and two sets of master events – the REB and automatic SEL3.

Promotional text: The waveform cross-correlation (WCC) method - based on the similarity of neighboring seismic sources and using a fixed station set - is an alternative method well suited to the nature of the aftershock sequences, i.e. similar repeating events.

P3.5-355 – Spot Check of Seismic and Infrasound Data and Products at the IDC Using Waveform Cross-Correlation and the REB Historical Events

Authors: Ivan Kitov[1]; Christos Saragiotis[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: ivan.kitov@ctbto.org

The Reviewed Event Bulletin (REB) of the IDC is the final product of interactive analysis, but also represents a set of seismic (S), infrasound (I), and SI events, which can be used for the analysis of the REB consistency. Continuous comparison of the event hypotheses obtained in routine automatic and interactive analysis with these historical events also helps to improve the REB completeness. More than 600,000 REB events have been converted into master events (MEs) with waveform templates at IMS seismic and infrasound stations. We use the method of waveform cross-correlation (WCC) to assess the similarity between event hypotheses and the MEs at a station-by-station

basis. For the hypotheses built in automatic processing (SEL1 to SEL3), only the MEs within 8 degrees from a given event hypothesis are used. For checking the REB, the best MEs within 4 degrees are used. In addition to checking the IDC bulletins, we process continuous SI data for missed events using a global set of ME selected as the most efficient in WCC detection of the historical REB events. All events obtained in the WCC processing are subject to the same spot check procedure as the SEL3 events.
Promotional text: Continuous comparison of the event hypotheses obtained in routine automatic and interactive analysis with historical events helps to improve the REB completeness.

P3.5-377 – Improving the Sensitivity for Radioxenon Beta–Gamma Measurements by Optimizing the ROI Limits for Each Sample

Author: Anders Ringbom[1]
[1]*Swedish Defence Research Agency (FOI), Stockholm, Sweden*
Corresponding Author: anders.ringbom@foi.se

Current techniques used for analyzing beta-gamma spectra measured by radioxenon systems are based on Regions-of-Interest (ROIs) covering relevant decay modes. The ROIs are set in the detector calibration procedure, and the same ROIs are used for all samples. However, the optimal ROI limits generally will be different for each sample. We present at new method where the optimal ROI settings are calculated for each sample by minimizing the MDA using differential evolution (DE), which is an optimization method used for real-valued multi-dimensional functions, not necessarily differentiable. For some detectors, we find that the MDA is decreased by up to 50%. Possible consequences for the standard analysis procedure used for radioxenon systems will be discussed.
Promotional text: This analysis method will improve the measurement sensitivity of radioxenon beta-gamma systems. For some systems, the improvement is very large, up to 50%.

P3.5-386 – An Algorithm for Determining the Moment of Occurrence of Changes in the Environment that Are Non-Linear and/or Non-Gaussian in Nature

Author: Miodrag Vracar[1]
Co-author: Stevo Vračar[2]
[1]*Faculty of Maritime Academic Studies, Belgrade, Republic of Serbia*
[2]*Comtrade Technology Center, New Belgrade, Republic of Serbia*
Corresponding Author: vracarmiodrag@mts.rs

This paper analyzes the possibility of applying higher - order statistics - third - order cumulants for isolation and autonomous determination of the moment of physical change in the observed environment. The proposed methods and algorithm make it possible to analyze all those phenomena: sound, infra sound, seismic and others that are essentially non-linear and non-Gaussian. As a result of the application of the algorithm, information was obtained about the occurrence of a given change, as well as the time when it happened precisely in an autonomous way. The application of the algorithm is important in all cases when the occurrence of events is stochastic and when it is necessary to provide constant monitoring and control without a man in the loop. The algorithm is especially important in all cases where it is necessary to register characteristic events that occur at relatively large distances from measuring sensors and when the information about the phenomenon is significantly distorted due to the processes that occur during transmission through medium: attenuation, multi path transmission and others.
Promotional text: When monitoring various phenomena that can occur in the natural environment, we pay special attention and interest to stochastic phenomena, which by their nature can be natural and/or artificial explosions, earthquakes, waves and the like.

P3.5-392 – Combining IMS and Non-IMS Seismic Stations Using CTBTO Distributed Software (NDC in a Box)

Authors: Haijun Wang[1]; Ronan Le Bras[1]; Alexander Poplavskiy[1]; Wolfgang Sommerer[1]; Leonid Kolesnykov[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: haijun.wang@ctbto.org

NDC-in-a-Box is an independent software package developed, distributed, and supported by PTS, which is intended for NDCs to establish a verification regime with a number of functions including receiving, archiving, processing and analysing data from IMS stations. To simplify installation and configuration of NDC-in-a-Box package, most software tools and applications are provided via a distributed virtual machine. SeisComP3, which has a large installed base, has been integrated into NDC-in-a-Box since 2016. Automatic data processing is now possible in addition to interactive data analysis. The standard way to configure non-IMS seismic stations is to use SeisComp3 scripts. Station parameters are imported into the OSDB database or saved as data files within the NDC-in-a-Box virtual machine. An alternative method is introduced here for configuration of non-IMS seismic stations. Based on basic parameters and instrument response file of non-IMS seismic stations, a program developed in Matlab is used to process stations parameters including calculation of instrument response parameters and export them into the database. Standard data files of non-IMS seismic stations can be accessed by NDC-in-a-Box via the shared folder of virtual machines, which simplifies the management of parameters for non-IMS seismic stations parameters and data exchange.

Promotional text: Based on basic parameters and instrument response file of non-IMS seismic stations, a program developed in Matlab is used to process stations parameters including calculation of instrument response parameters and export them into the database.

P3.5-407 – Testing the Forensic Radionuclide Event Analysis and Reconstruction Tool (FREAR)

Author: Ian Hoffman[1]
Co-authors: Noah Hladun[1]; Kurt Ungar[1]; Pieter De Meutter[2]; Andy Delcloo[3]; Alain Malo[4]; Nils Ek[5]; Yves Pelletier[5]; Zaneta Gacek[6]; Astrid Suarez-Mullins[6]; Michael Walters[6]; John Shuford[6]; Matthew Goodwin[7]; Ashley Davies[7]
[1]*Radiation Protection Bureau, Health Canada, Ottawa, ON, Canada*
[2]*Belgian Nuclear Research Centre (SCK-CEN), Mol, Belgium*
[3]*Royal Meteorological Institute of Belgium, Belgium*
[4]*Canadian Meteorological Centre, Canada*
[5]*Meteorological Service of Canada, Ottawa, ON, Canada*
[6]*Air Force Technical Applications Center (AFTAC), FL, USA*
[7]*AWE Aldermaston, Reading, United Kingdom*
Corresponding Author: ian.hoffman@canada.ca

The recently developed open source FREAR tool improves nuclear event analysis by using Bayesian inference principles to estimate key source term parameters using measurements from distant radionuclide monitoring equipment in combination with Atmospheric Transport and Dispersion Models (ATDM). Trials on real world reconstructions have demonstrated clear and dramatic improvements over standard correlation techniques, such as the Possible Source Region (PSR) algorithm. The improvements in source characterization are a result of implementing a statistical non-detection model that accurately represents the performance of the radionuclide detection equipment and by using a full ATDM uncertainty model in the reconstruction process. To further test the performance and capabilities of this tool, two blind tests are conducted with synthetic source terms with short and long-range transport. The test scenarios and the results of the reconstruction are described and assessed to further demonstrate the compelling benefits of using the FREAR statistical tool in event analysis.

Promotional text: The Forensic Radionuclide Event Analysis and Reconstruction Tool is a new method to improve nuclear test monitoring and verification by applying statistical inference methods to reconstruct the emission source by fusion of radionuclide data and atmospheric transport modelling.

P3.5-442 – A New Algorithm for Processing Beta–Gamma Coincidence Spectra Based on the Maximum Likelihood Estimation

Author: Nikolay Sidorov[1]
Co-authors: Dobrynya Timofeev[1]; Daniil Molodtsev[1]; Mikhail Chernov[1]
[1]*All-Russia Research Institute of Automatics named after N. L. Dukhov (VNIIA), Moscow, Russian Federation*
Corresponding Author: sidorov785@mail.ru

A new algorithm for processing beta-gamma coincidence spectra based on the maximum likelihood and non-negative least squares (NNLS) methods is presented. The algorithm allows simultaneous processing of the signal in all regions of interest (ROI). This approach has a number of advantages over the net count calculation (NCC) algorithm and provides a solution to the problem of processing beta-gamma spectra in its most general form. The use of regions of interest (ROI) with simultaneous NNLS fitting allows efficient and noise-resistant estimation of the activity of relevant xenon isotopes. The presented method also makes it possible to process measurement errors in a more general and correct form. A linear regression solution is used to calculate the errors, which makes it possible to take into account the correlations of obtained activity estimates. A program was developed for processing beta-gamma spectra using a new algorithm, and the activities and volumetric activities of xenon were calculated using the data obtained by the Monitoring System of Xenon Isotopes MIKS in 2020. The results of the new measurement processing algorithm and other algorithms are compared.

Promotional text: A new algorithm for processing beta-gamma coincidence spectra based on the maximum likelihood method is presented. The calculation of the activity of xenon was carried out according to the data obtained from the MIKS system.

P3.5-453 – The Coda Calibration and Processing Tool: Java-Based Freeware for the Geophysical Community

Author: Kevin Mayeda[1]
Co-authors: Justin Barno[2]; Rengin Gok[2]; Jorge Roman-Nieves[1]; William Walter[2]
[1]*Air Force Technical Applications Center (AFTAC), FL, USA*
[2]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: kevin.mayeda@gmail.com

The coda magnitude method of Mayeda and Walter (1996) provides stable source spectra and moment magnitudes (Mw) for local to regional events from as few as one station that are virtually insensitive to source and path heterogeneity. The method allows for a consistent measure of Mw over a broad range of event sizes rather than relying on empirical magnitude relationships that attempt to tie various narrowband relative magnitudes (e.g., ML, MD, mb, etc.) to absolute Mw derived from long period waveform modeling. The Coda Calibration Tool (CCT) stems from a multi-year collaboration between the US NDC and LLNL scientists with the goal of developing a fast and easy Java-based, platform independent coda envelope calibration and processing tool. We present an overview of the tool and advantages of the method along with several calibration examples, all of which are freely available to the public via GitHub (https://github.com/LLNL/coda-calibration-tool). Once a region is calibrated, the tool can then be used in routine processing to obtain stable source spectra and associated source information (e.g., Mw, radiated seismic energy, apparent stress, corner frequency, source discrimination on event type and/or depth). We welcome future collaboration, testing and suggestions by the geophysical community.

Promotional text: CCT provides a fast and efficient means of calibrating and processing local and regional coda envelopes to estimate stable source spectra, Mw, and apparent stress, that are roughly 3-to-4 times less variable than estimates derived from traditional direct wave estimates.

P3.5-476 – IMS Data Fusion and the Possibilities of Dempster-Schafer Theory

Author: Ian Hoffman[1]
Co-authors: Giselle Fernandez[2]; Donald Lucas[2]; Lee Glascoe[2]; Stephen Myers[2]
[1]*Radiation Protection Bureau, Health Canada, Ottawa, ON, Canada*
[2]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: ian.hoffman@canada.ca

The International Monitoring System (IMS) is comprised of multiple types of sensors that provide verification information. While each piece of information is useful for verification, the full benefit of multi-technology measurements has not been fully taken advantage of. Data Fusion is an approach that seeks to integrate disparate sources of data into a unified and comprehensive event analysis. Several approaches (*e.g.* cost-function analysis, Bayesian inference) have demonstrated the power and benefit of data fusion approaches for Treaty verification. However, an important problem in the data fusion process arises when not all information is consistent, or believable. Dempster-Schafer theory provides a statistical means to reconcile evidentiary beliefs in the data fusion process. This poster will describe how inconsistent evidence may arise within the IMS, and show how Dempster-Schafer theory can help to reconcile evidence in a data fusion process and support the event analysis process for National Data Centres. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. This abstract is LLNL-ABS-817217-DRAFT.

Promotional text: Uncertainty characterization is crucial in data fusion processes (e.g. inference techniques) that combine evidence from multiple sources. When pieces of evidence are inconsistent, applying Dempster-Schafer theory reconciles the inconsistencies and improves the inference process.

P3.5-483 – Method for Assessing ^{37}Ar Emissions from Nuclear Reactors

Authors: Martin B. Kalinowski[1]; Pouneh Tayyebi[2]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Iran Nuclear Regulatory Authority, Tehran, Iran*
Corresponding Author: martin.kalinowski@ctbto.org

^{37}Ar is an indicator of an underground nuclear explosion. This radioisotope is produced via ^{40}Ca (n, α) ^{37}Ar reaction through neutron activation of ^{40}Ca included in the rocks near to the nuclear explosion location. The relatively long half-life of 35 days compared to CTBT-relevant radioxenon isotopes results into ^{37}Ar activity becoming stronger than radioxenon activity approximately 50 days after detonation. Normal operational releases of ^{37}Ar from nuclear facilities contributes to the atmospheric background. It can be produced via neutron activation of air or of gas dissolved in water. The emissions of this isotope are not regularly measured and very few release data are available. Therefore, the two-step method presented here is more complex than the method the authors had applied previously for assessing ^{37}Ar releases from nuclear research reactors. As the first step, simulations with ORIGEN determine isotopic ratios of ^{37}Ar and an appropriate proxy like ^{41}Ar for which stack release data are available. These ratios are depending on the duration of the irridiation and the intensity of the neutron flux. As second step, the retention time is used to account for the decay between escaping the neutron flux and getting released through the stack.

Promotional text: ^{37}Ar is important as indicator of an underground nuclear explosion. Nuclear power plant emissions contribute to the ambient background and needs to be assessed. This presentation describes a method how to achieve this.

P3.5-507 – Is There a Potential for Further Enhancing IDC Spectrum Analysis Methods of CTBT Radionuclide Measurements after 25 Years of Progressive Development?

Authors: Boxue Liu[1]; Martin B. Kalinowski[1]
Co-authors: Abdelhakim Gheddou[1]; Lars-Erik De Geer[2]; Matthias Zähringer[3]; Mika Nikkinen[4]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Swedish Defence Research Agency (FOI), Sweden (Retired)*
[3]*Federal Office for Radiation Protection (BFS), Freiburg, Germany*
[4]*International Atomic Energy Agency (IAEA), Vienna, Austria*
Corresponding Author: boxue.liu@ctbto.org

This presentation is an overview on radionuclide analysis procedures at the IDC. There are three sets of approaches currently, the single channel analyser curve for particulate, the least squares regression on gamma- and X-rays peaks of xenon isotopes for high resolution spectra and the net count calculation method for beta-gamma coincidence spectra for noble gas, which are based on conventional frequentist statistics. Most daily IMS spectra have low counts close to background level. Decision thresholds by Currie's definition have been found to tend being underestimated, resulting in false positive detections. Enhancements on current methods could apply optimization regression analyses of standard spectra, 3-D fitting and gross counts, or machine learning which all are consistent with ISO standards on estimation of measurement uncertainty and characterization limits based on Bayesian statistics. Probability distributions of measurands, e.g. activity, concentration and isotopic ratio, could be obtained by the Monte-Carlo method, directly based on distributions of inputs of measurement spectra, calibration data and related parameters, resulting in realistic estimates for measurands, their uncertainties and associated limits of the coverage interval with a given probability. IDC radionuclide analysis reports could be enhanced by reporting not only results and their uncertainties but also associated characterization limits.

Promotional text: The overview on past achievements and potential developments of radionuclide analysis procedures at the IDC reveals the challenge to enhance estimation of measurement uncertainty and characterization limits, improving analysis reliability.

P3.5-508 – Monte Carlo Calculations of Isotopic Ratios of Fission Products Detected at IMS Radionuclide Stations

Authors: Boxue Liu[1]; Martin B. Kalinowski[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: boxue.liu@ctbto.org

Activity ratios of paired isotopes detected at IMS radionuclide stations can be used to not only discriminate a nuclear test from civil nuclear releases, but also determine the explosion time under assumed scenarios. A function of the isotopic ratio with time from the explosion time up to the stop of collection can be derived, based on Bateman equations of given decay chains. It is not a linear relationship between activities collected in the sample and concentrations in the plume. Activities in the sample are determined by spectra analysis. Non-linear relationships of isotopic ratios can also be caused by the division algorithm when denominators have larger measurement uncertainties. Covariances between isotope concentrations might be another reason for non-linearity. Correlations of two concentrations could be caused by decay corrections of parent-daughter chain, interference corrections between two isotopes and subtractions of the same detector background measurement. This presentation demonstrates Monte-Carlo procedures estimating the probability distributions of isotopic ratios, based on input distributions related to spectrum measurements and decay chains. Then the isotopic ratio, associated uncertainty and limits of the coverage interval can be estimated accordingly. Furthermore, the explosion time can be estimated in the same way, if applicable.

Promotional text: This presentation is about calculation procedures of isotopic ratios by the Monte-Carlo method. It is a simple and direct way to perform uncertainty estimation for numerical solutions of the isotopic ratio and explosion time.

P3.5-511 – An Alternative Proposal for Estimation of Body Wave Magnitude Taking Account of Noise Magnitudes

Authors: David Steinberg[1]; Anat Kinamoni[1]; Yochai Ben-Horin[2]; Yael Radzyner[2]
[1]*Tel-Aviv University, Israel*
[2]*Soreq Nuclear Research Center, Yavne, Israel*
Corresponding Author: dms@tauex.tau.ac.il

Magnitude measures the strength of an earthquake and is an important parameter for earthquake / underground test discrimination. The IDC computes body magnitudes from the amplitude to period ratio recorded at network stations. Radzyner et al. (2017) showed that there was superior consistency of magnitudes across stations when the magnitude is computed as a linear function of the ratio, but with a slope that could differ from 1. The slopes and intercepts that describe these lines were found to be station-specific. We extend the method by also including noise magnitude measurements in determining the station corrections. This follows the maximum likelihood (ML) magnitude estimation approach of Ringdal (1976), later applied to offset estimation for IDC data by Zaslavsky-Paltiel and Steinberg (2008). We develop an optimization algorithm that finds joint ML estimates for the station-specific parameters that link observed seismic signals to event magnitude, taking account of noise magnitudes, as well as computing the event magnitudes themselves. The procedure is applied to a large database of IDC events and to primary stations. We find strong support for the general, but station-specific, linear relationship proposed by Radzyner et al. for computing body wave magnitude from the amplitude to period ratio.

Promotional text: This work presents an alternative algorithm for computing body wave magnitudes which incorporates both recorded magnitudes and noise magnitudes. There is extensive analysis of IDC data.

P3.5-550 – Development of a Processing Toolkit for In-Depth Radionuclide Data Analysis: Case Study for the Period of 2017–2020 IMS Detections

Authors: Mohammad Javad Safari[1]; Fatemeh Masjedi[1]
[1]*Amirkabir University of Technology (AUT), Tehran, Iran*
Corresponding Author: mjsafari@aut.ac.ir

IMS radionuclide concentration data is accessible through the CRTooL. It contains detected concentrations for all kinds of radionuclides, categorized as noble gas (Xenon) and particulates, standing for natural, activation and fission-products. The ultimate role of these data is to find and then identify any event that is related to the verification regime of the CTBT. Identification of events demands data visualization to look for different aspects of data. Here, we obtained offline CSV files for the period of 2017-2020 taken from CRTool, with appropriate tags declaring detection location, country, region and the kind of radionuclide. Then, a toolkit has been developed for parametric study of these data. There are several types of graphics produced for the in-depth analysis of data: a bar chart to show the concentration of all radionuclides for any single station and a bar chart to show the concentration of a radionuclide for all stations, probably within a region/country. It also is possible to produce animated graphics, for a daily, weekly or monthly variation of concentrations. This may be displayed by bubble chart graphics over a geographic map for any single radionuclide.

Promotional text: Currently, CRTool is limited to very simple data visualization and graphics capabilities. This work helps to renew the design of CRTool data analysis and visualization graphics, and brings several ideas for still and animated graphical representations of data.

P3.5-561 – Massive Earthquake Detection Techniques: Matched Filter and Fingerprinting

Authors: Guillermo Gonzalez[1]; Allen Husker[1]
[1]*Instituto de Geofisica, Universidad Nacional Autónoma de Mexico, Mexico City, Mexico*
Corresponding Author: geomem.gg@gmail.com

Seismology data analysis is becoming a challenge due to the exponential growth of continuous data being stored. In this study we present and compare two methods to massive detect earthquakes: the matched filter and fingerprinting. We have tested matched filter over several study zones of interest: in the Western part of Mexico to study general seismic activity, in the Isthmus of Tehuantepec in Southern Mexico to track aftershocks from the September, 2018 Mw8.2 earthquake, and in the North Pole to study seismic activity mainly caused by ice cracking, or ice-quakes. We have demonstrated the accuracy of this technique especially detecting low amplitude signals hidden in the noise and coming out when we stack the resulting correlation coefficients over multiple stations. We are now testing fingerprinting, a technique much more efficient computationally, where we focus on extracting a fingerprint of the waveform for several templates in the time-frequency domain by compressing the resulting scalogram at different time steps. The information for each time step for every template is stored. We then perform a similarity search computing the Jaccard similarity and the probability for each query signal to every template, so that we can classify similar events automatically.

Promotional text: Seismology data analysis is becoming a challenge due to the exponential growth of continuous data being stored. In this study we present and compare two methods to massive detect earthquakes: the matched filter and fingerprinting techniques.

P3.5-584 – Integration of a Generalized-F Detector at the IDC and US NDC

Authors: Thomas VanDeMark[1]; Jeffrey Given[2]
[1]*Air Force Technical Applications Center (AFTAC), FL, USA*
[2]*Leidos, Reston, VA, USA*
Corresponding Authors: thomas.vandemark.1@us.af.mil, jeffrey.w.given@leidos.com

Selby, (2008, 2011) developed a Generalized-F method, (Gen-F), to enable application of an F-statistic detector to small-aperture arrays where correlated background noise would otherwise degrade performance; and in 2013, he introduced an innovative time-frequency approach that further enabled application of Gen-F to arrays independent of aperture. Tests of the method on the IMS arrays have shown that the Gen-F detector out-performs the current detector in use at the IDC for many of the arrays, both increasing valid detections, while decreasing their overall number. The UK NDC contributed software based on Selby's 2013 method, and the US NDC integrated it into the DFX detection framework in use at the IDC and US NDC. The Gen-F detector is implemented as a module fully compatible with the input and output of the existing DFX framework and is compatible with the subsequent down-stream station and network processing, (StaPro, GA, NetVISA). The US NDC is tuning the Gen-F parameters that frame an isotropic noise model to suppress correlated noise at regional, small-aperture arrays. Using a multi-day, analyst-reviewed set of detections as ground-truth, and the observed interstation correlation, the US NDC will demonstrate the impact of tuning these Gen-F parameters at one (1) regional array.

Promotional text: The abstract denotes a potential improvement in seismic signal detection processing applied within the constructs of the DFX detection framework.

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

P3.5-610 – On the Requirements for Validation Data Sets in Potential Future Scientific Projects for Enhancing and Developing Methods to Highlight Possible Nuclear Explosion Signatures in Radionuclide Monitoring

Author: Martin B. Kalinowski[1]
Co-authors: Jolanta Kusmierczyk-Michulec[1]; Boxue Liu[1]; Anne Tipka[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: martin.kalinowski@ctbto.org

The discrimination between the highly variable radioxenon background caused by normal operations of nuclear facilities and CTBT-relevant events is a challenging but crucial task. For this reason, the radioxenon background at IMS noble gas systems must be sufficiently characterized and understood. The scientific methods and software tools to do this can still be significantly enhanced. This presentation summarizes relevant scientific project line-outs that would serve this purpose and make use of atmospheric transport modelling (ATM). These include methods for associating multiple samples to the same release event, provision of higher source location estimates, developing of the screening flag "ATM backtracking to known sources", corrections to ATM in case of systematic discrepancies between observed and simulated concentrations from a known source due to complex terrain, land sea breeze, and mountains, as well as the use of isotopic ratio measurements for screening. For each of these possible projects, the atmospheric radioxenon measurement data required for developing and validating the methods and tools is described. These build on IMS noble gas measurements possibly supplemented by data from temporary experiments with transportable noble gas measurement systems.
Promotional text: This presentation describes possible scientific projects to develop among others methods for associating multiple samples to the same radionuclide release event, for backtracking to known sources. It describes what radioxenon measurement data are required to validate the results.

T3.6 Artificial Intelligence and Machine Learning

Highlights

O3.6-400 described improvements to the NET-VISA error estimates. NET-VISA is a physics based generative model of global scale seismology. The model and its associated inference algorithm have been deployed by the IDC to generate the VSEL3 bulletin of events, which is used by the analysts to generate the Late Event Bulletin. The current version of the inference algorithm relies on the existing IDC libraries to compute the error/coverage ellipse of events. In this work, a new module was added to directly use the NET-VISA model to obtain more accurate estimates of 90 per cent confidence ellipses with Markov Chain Monte Carlo (MCMC) methods.

O3.6-118 described Deep Learning Travel Time (DeLTTa), a deep learning method and computer code for emulating seismic phase travel times that is based on a 3-D earth model. After training, the machine learning computer code is approximately 10 megabytes in size, and travel times are computed in approximately 10 microseconds on a single central processing unit. Currently achieved prediction accuracy is approximately .5s (2s), which is similar to the inherent accuracy of the 3-D model. With additional development, DeLTTa will enable easy use of 3-D models in routine seismological processing and analysis.

O3.6-148 reported on the development of an algorithm for automatic identification of repeating seismic events such as aftershocks and mine explosions. Identification of such events will help to improve the quality of automatic bulletins and to lighten the burden on analysts. The algorithm constructs a diffusion map, a low-dimensional representation of the examined data, by using a variant of a non-linear dimensionality reduction algorithm. This enables the data to be split into one cluster that contains the repeating events and another cluster that holds the other processed waveforms that are not related to the examined events of interest. In P3.6-111, a discrimination method based on diffusion maps was configured and applied for discrimination of seismic events in the Sea of Galilee. Five seismic events whose epicentres lie near the Sea of Galilee were reported by the CTBTO in July 2018. Notably, three out of the five events were not screened out by the CTBTO as natural events, even though they were a part of a swarm of earthquakes. In this work, utilizing waveforms of the Israel Cooperating National Facility (CNF) station, a machine learning method correctly classified as earthquakes all July 2018 Sea of Galilee seismic events with durational magnitude Md >2.3.

P3.6-197 demonstrated discrimination between earthquakes and quarry blasts using a committee machine that combined supervised and unsupervised artificial neural networks. The unsupervised network was used as a measure of accuracy for the results of the supervised neural network. The artificial neural networks were trained using different input parameters, which are the P wave spectrum corner frequency (PcF), S wave corner frequency (ScF), and the ratio (Rcf) of PcF to Scf. The combined approach succeeded in discriminating between earthquakes and quarry blasts in northern Egypt. Repeated events were also the topic of P3.6-326, which focused on seismic arrays, introducing a 2-D convolutional layer that encodes the propagation time delays between array stations. P3.6-269 discussed unsupervised deep learning for identifying seismic event classes in signal-rich records for environmental monitoring in Norway (glaciers and an unstable rock slope). Pre-trained convolutional neural networks (CNNs) were used for image recognition of spectrograms of three component seismic data. A CNN was also used in P3.6-541 for the detection of local events under the global sparse seismic network. The principle that the P wave and S wave velocity ratios of local earthquakes in the regional network are consistent was used in the association of seismic phases from multiple stations.

P3.6-131 discussed an approach to regularization and semi-supervised learning for seismic event analysis. In seismic event processing, enforcing consistency over disparate observations for an individual event has a long history of empirical value. The presentation showed how to formulate this expectation as a loss term during model training and shared several examples of how this expectation can result in better model regularization, which can reduce overfitting while still outperforming other methods, give us more trustworthy decision confidence, and allow the leverage of data where no ground truth is available.

P3.6-143 applied a paired neural network (PNN) to aftershock identification. Large aftershock sequences cause problems for the IDC because the seismic event rate increases dramatically during an aftershock sequence, making correct association of arrivals difficult for the automated pipeline. A PNN was trained to automatically perform aftershock identification based on waveform similarity.

P3.6-124 implemented a seismic denoising method that uses a trained deep CNN model. The short-time Fourier transform (STFT) of the estimated signal is obtained by multiplying the signal mask with the STFT of the input signal. Application to real data suggests that the denoiser achieves on average a factor of up to ~2–5 improvement in the signal to noise ratio over bandpass filtering and can suppress many types of noise that bandpass filtering cannot.

Infrasound

P3.6-615 presented an effort to develop a new generation of deep neural network that takes advantage of basic universal laws to predict the background infrasound noise. A neural network architecture is proposed that uses additional layers to embed properties on the stochastic parameterization used to represent the atmospheric randomness. The neural network model is trained on data from IMS stations, using far-field self-sustained natural events such as microbaroms and high fidelity simulation data. This neural network architecture can be used in combination with probabilistic Bayesian models to improve network processing (detection, association) as well as our understanding of atmospheric variability.

O3.6-205 proposed a physics based data augmentation method to produce an entirely synthetic training data set for machine learning analysis of long range infrasound signals. Realistic source time functions are generated and propagated through modelled atmospheres out to several hundred kilometres, thus producing a catalogue of synthetic events. These data are then used to train a time convolutional neural network that classifies explosions and background noise. The presentation demonstrated that the time convolutional neural network not only identifies modelled events but is also effective at detecting and characterizing real world explosive transients.

P3.6-622 introduced a new strategy to reduce wind noise in the recorded signals of IMS stations. This strategy is based on using machine learning to extract turbulence noise from data than can be translated into knowledge about the underlying fluid mechanics. The work proposes to improve station processing by characterizing the noise due to turbulence in the atmospheric boundary layer using neural networks. The performance was assessed using real world signals recorded at several infrasound stations of the IMS, over days and nights, and during different seasons.

Radionuclides

O3.6-225 and P3.6-509 proposed a model of beta–gamma coincidence radioxenon spectra classification by deep learning (CNN technique) as pre-screening for CTBT-relevant samples. The CNN technique was applied using 2012–2019 real data from the noble gas system at radionuclide laboratory RN75 (USA). Automatic classification was shown to have high accuracy, even without utilizing background spectra, interference corrections or determining the activity concentration of each isotope. The authors claimed that by synthesizing nuclear engineering and deep learning disciplines, experts can accelerate and optimize the review process of background and CTBT-relevant samples by an average accuracy of 92 per cent and 98 per cent respectively.

P3.6-516 applied automatic radionuclide detection using deep neural networks to gamma ray detector data obtained from public data available from Oak Ridge National Laboratory (ORNL) (USA). The data set contains six different types of source combinations: high enriched uranium, ^{137}Cs, ^{131}I, ^{60}Co, technetium and low enriched uranium. Experiments on simulated spectra suggest that deep learning methods (recurrent neural networks (RNNs) and long short-term memory (LSTM)) can achieve a higher F1 score under difficult testing conditions compared with the best performing traditional machine learning models, obtaining a 91.11 per cent score during evaluation.

On-Site Inspection

Artificial intelligence vision technology relies on a large database for model training and could cause concern with regard to maintaining the balance between OSI operational efficiency and intrusiveness. P3.6-439 carried out a preliminary study of the application of artificial intelligence and machine learning vision technology to assist OSI operations. P3.6-096 described a system solution to support the management of the living and working areas of the OSI inspection team and the inspected State Party, based on AI-related hardware learning and self deep learning. System functionality involves personnel detection, image classification and recognition. The entire system combines thermal, daylight/CCTV and laser lighting and range finding with application software.

03.6 Artificial Intelligence and Machine Learning Abstracts of Oral Presentations

03.6-118 – Emulation of Seismic Phase Travel Times Using the Deep Learning Travel Time (DeLTTa) Method

Author: Stephen Myers[1]
Co-authors: Gemma Anderson[1]; Derek Jensen[1]
[1]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
Corresponding Author: myers30@llnl.gov

Deep Learning Travel Time (DeLTTa) is a deep-learning method and computer code for emulating seismic-phase travel times that are based on a 3-dimensional (3D) Earth model. Greater accuracy of travel time predictions using a 3D Earth model are known to reduce the bias of event location estimates and improve the process of associating detections to events. However, practical use of 3D models is challenged by slow computational speed and the unwieldiness of pre-computed lookup tables. DeLTTa trains a deep-learning network using pre-computed travel times, resulting in a compact and computationally fast way to approximate travel times based on a 3D Earth model. DeLTTa is trained using approximately 850 million P-wave travel times based on the LLNL-G3D-JPS model from randomly sampled event locations to 10,393 global seismic stations. After training, the machine learning computer code is approximately 10 Mbytes in size and travel times are computed in approximately ten micro-seconds on a single CPU. Currently achieved prediction accuracy is approximately ½ second at the 2-sigma level, which is similar to the inherent accuracy of the 3-D model. With additional development, DeLTTa will enable easy use of 3-D models in routine seismological processing and analysis.
Promotional text: 3D Earth models can improve seismic travel-time prediction accuracy, which leads directly to more accurate event locations. Machine learning efficiently emulates travel-time calculations, opening the possibility of using state-of-the-art Earth models in the operational system.

03.6-148 – Identification of Repeating Seismic Events Using Non-Linear Dimensionality Reduction

Authors: Yuri Bregman[1]; Itay Niv[2]; Neta Rabin[2]
[1]*Soreq Nuclear Research Center, Yavne, Israel*
[2]*Tel-Aviv University, Tel-Aviv, Israel*
Corresponding Author: ybregm@gmail.com

In this work, we develop an algorithm for automatic identification of repeating seismic events such as aftershocks and mine explosions. Identification of such events will help to improve the quality of automatic bulletins and to lighten the analysts' burden. The algorithm constructs a low-dimensional representation of the examined data by using a variant of a non-linear dimensionality reduction algorithm named diffusion maps. The proposed methods begin with a pre-processing stage in which a time–frequency representation is extracted from each seismogram while capturing common properties of seismic events and overcoming magnitude differences. Then diffusion maps are used in order to construct a low-dimensional model of the original data. This enables to split the data into one cluster that contains the repeating events and another cluster that holds of the other processed waveforms, which are not related to the examined events of interest. The algorithm's performance is demonstrated on several seismic data sets that were recorded at IMS stations. In particular, at the IMS station EIL we identify arrivals that were caused by the blasts at the nearby Eshidiya mine in Jordan. Identification and masking of such arrivals should reduce the number of false associations in the automatic bulletins.
Promotional text: We develop an algorithm for automatic identification of repeating seismic events such as aftershocks and mine explosions. Identification of such events will help to improve the quality of automatic bulletins and to lighten the analysts' burden.

O3.6-205 – Using Machine Learning to Detect and Characterize Long Range Infrasound Signals from High Explosives

Author: Alex Witsil[1]
Co-authors: David Fee[1]; Philip Blom[2]; Joshua Dickey[3]
[1]*University of Alaska Fairbanks, Fairbanks, AK, USA*
[2]*Los Alamos National Laboratory (LANL), Los Alamos, NM, USA*
[3]*Air Force Technical Applications Center (AFTAC), FL, USA*
Corresponding Author: ajwitsil@alaska.edu

The International Monitoring System (IMS) infrasound network is well positioned to record atmospheric nuclear explosions, but algorithmically classifying and characterizing these events is challenging. Difficulties stem from the variable and dynamic atmosphere that modulates acoustic transients at regional to global distances. Machine learning (ML) is well suited to classify infrasound activity but generally requires large training datasets. However, data from the relatively few large chemical explosions and sparse global infrasound network are insufficient to train a ML model given how complex and dynamic the atmosphere is at global scales. Instead, we propose a physics-based data augmentation method to produce an entirely synthetic training dataset. Realistic source time functions are generated and propagated through modeled atmospheres out to several hundred kilometers, thus producing a catalog of synthetic events. These data are then used to train a time convolutional neural network (TCN) that classifies explosions and background noise. We show the TCN not only identifies modeled events but is also effective at detecting and characterizing real world explosive transients, including those from the Humming Roadrunner experiments. This work was supported by the Nuclear Arms Control Technology (NACT) Program at Defense Threat Reduction Agency (DTRA). Approved for public release; Distribution is unlimited.

Promotional text: We present a new infrasound based method to detect and classify nuclear blasts using machine learning. This approach will help elevate the usefulness of global infrasound deployments as a tool to monitor for atmospheric nuclear activity.

O3.6-225 – Beta–Gamma Coincidence Radioxenon Spectra Classification Using the Convolution Neural Network (CNN) Technique

Author: Sepideh A. Azimi[1]
Co-authors: Hossein Afarideh[1]; Martin B. Kalinowski[2]; Radek Hofman[2]; Abdelhakim Gheddou[2]
[1]*Amirkabir University of Technology (AUT), Tehran, Iran*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: azimi.bme@gmail.com

In this study, using a machine learning method, in particular, a deep learning approach, we propose for the first time a model of Beta-Gamma coincidence radioxenon spectra classification. Specifically, by means of real data from the noble gas system in Charlottesville (USX75) as part of the International Monitoring System (IMS) operated by CTBTO between 2012 and 2019, we apply the convolution neural network (CNN) technique based on the absolute concentration of each radioxenon isotope. The results show that without utilizing background spectra, interference corrections, and without determining the activity concentration of each isotope, the automatic classification can be carried out with high accuracy. This implies that categorization through deep learning does not require the knowledge of screening threshold values that are applied for sample categorization after applying the Net Count Calculation (NCC) analysis method used currently by the International Data Centre (IDC) of the CTBTO. Our results support that by synthesizing nuclear engineering and deep learning disciplines, experts can accelerate and optimize the review process of background and CTBT-relevant samples by an average accuracy of 92% and 98% respectively.

Promotional text: Classification of Beta-Gamma coincidence raw radioxenon spectra by deep learning (CNN technique) as pre-screening for CTBT relevant samples.

O3.6-400 – Markov Chain Monte Carlo Estimate of Origin Error for Seismic, Hydroacoustic, Infrasound Events in NET-VISA

Authors: Nimar Arora[1]; Geeta Arora[1]
Co-authors: Noriyuki Kushida[2]; Ronan Le Bras[2]
[1]*Bayesian Logic, CA, USA*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: nimar.arora@gmail.com

NET-VISA is a Physics-Based Generative Model of global scale seismology. The model includes a description of the generation of events which include under-water and atmospheric events, the propagation of waveform energy from the events in multiple phases, and the detection or mis-detection of these phases at the network of stations maintained by the International Monitoring System (IMS) as well as a model of noise processes at these stations. The model and its associated inference algorithm has been deployed by the International Data Center (IDC) to generate a bulletin of events known as VSEL3. This bulletin is currently being used by the analysts to generate the LEB bulletin and in future it is planned to replace the current GA-based SEL3 bulletin with VSEL3. The current version of the inference algorithm relies on the existing IDC libraries to compute the error/coverage ellipse of events. In this work we have added a new module to directly use the NET-VISA model to estimate the 90 per cent confidence ellipse. We describe the details of the Markov Chain Monte Carlo (MCMC) estimation and demonstrate on a study of ground truth events from the International Seismological Center (ISC) that the new confidence ellipses are more accurate.

Promotional text: MCMC estimate of origin errors added to NET-VISA.

P3.6 Artificial Intelligence and Machine Learning Abstracts of Poster Presentations

P3.6-096 – Artificial Intelligence Enabled System for OSI Inspection Team/Inspected State Party Living/Working Area Management

Author: Peng Li[1]
Co-authors: Zhen Wang[1]; Libin Niu[1]; Jing Yang[1]; Xinmin He[1]; Yuan He[1]
[1]*Hope Investment Development Corp. Ltd., Beijing, China*
Corresponding Author: lipeng1406@163.com

According to OSI Operation Manual, IT/ISP living and working areas should be well-protected. Scenarios like the management of the different living and working areas for IT and ISP, require entry permission granted separately to either IT or ISP members. This work would provide a customized management supporting system solution to the above mentioned scenario. The system is based on Artificial Intelligence (AI) related hardware learning and self-deep learning. System functionality involves personnel detection, image classification and recognition. The whole system combines thermal, daylight/CCTV and laser lighting/range-finding with application software. It also supports dynamic and static targets detection and recognition including human, animal, vehicle, smoke, fire and high-temperature items, with AI functions of detection, recognition, classifications, and reactions like alarm, denied access. IT/ISP members' image could be pre-loaded into the system, which would grant permission to IT/ISP individuals or deny their access. The system could be compatible with OSI IIMS and other third-party systems. The system also supports area intrusion/leave/behavior analysis. In order to achieve high level image recognition, the deep-learning software could work under harsh environment by intelligence function such as defog, background analysis and area shield. Individual privacy issues would be jointly and legally solved together with the PTS.

Promotional text: This work carried out a system solution to

OSI IT/ISP living and working areas management supporting system, based on Artificial Intelligence (AI) related hardware learning and self-deep learning.

P3.6-111 – Machine Learning Based Earthquakes Explosion Discrimination for Sea of Galilee Seismic Events of July 2018

Authors: Yuri Bregman[1]; Yael Radzyner[1]; Yochai Ben-Horin[1]; Neta Rabin[2]
[1]*Soreq Nuclear Research Center, Yavne, Israel*
[2]*Tel-Aviv University, Tel-Aviv, Israel*
Corresponding Author: ybregm@gmail.com

Discrimination between earthquakes and explosions is an essential component of nuclear test monitoring. Discrimination methods currently used by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) are often ineffective for regional events, particularly in Israel's region. For instance, five seismic events whose epicenters lie near the Sea of Galilee (Lake Kinneret) were reported by the CTBTO in July of 2018. Those were relatively strong regional events, which were observed by stations hundreds of kilometers from the epicenter. Notably, three out of those five events were not screened out by the CTBTO as natural events, though they were a part of a swarm of earthquakes. In this work, the diffusion maps-based discrimination method is configured and applied for discrimination of the July 2018 Sea of Galilee seismic events. Utilizing waveforms of the Israel Cooperating National Facility (CNF) station HRFI, we show that this machine learning method correctly classifies as earthquakes all July 2018 Sea of Galilee seismic events with durational magnitude Md > 2.3. **Promotional text**: In this work, the diffusion maps-based discrimination method is configured and applied for discrimination of the July 2018 Sea of Galilee seismic events.

P3.6-124 – Deep Learning Denoising Applied to Regional Distance Seismic Data in Utah

Author: Rigobert Tibi[1]
Co-authors: Patrick Hammond[1]; Ronald Brogan[2]; Christopher Young[1]; Keith Koper[3]
[1]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
[2]*ENSCO, Inc. Springfield, VA, USA*
[3]*Department of Geology and Geophysics, University of Utah, Utah, USA*
Corresponding Author: rtibi@sandia.gov

Seismic waveform data are generally contaminated by noise from various sources. To date, the most common noise suppression methods have been based on frequency filtering. These methods, however, are less effective when the signal of interest and noise share similar frequency bands. We implemented a seismic denoising method that uses a trained deep convolutional neural network (CNN) model. In our approach, the CNN provides a signal mask and a noise mask for an input signal. The Short-Time Fourier Transform (STFT) of the estimated signal is obtained by multiplying the signal mask with the STFT of the input signal. To build and test the denoiser, we used compiled signal and noise datasets of seismograms recorded by the University of Utah Seismograph Stations network (United States). Results of test runs involving more than 9,000 constructed waveforms suggest that on average the denoiser improves the SNRs by ~5 dB and that most of the recovered waveforms have high similarity with respect to the target waveforms and suffer little distortion. Application to real data suggests that our denoiser achieves on average a factor of up to ~2-5 improvement in SNR over bandpass filtering and can suppress many types of noise that bandpass filtering cannot. **Promotional text**: This study aligns with the SnT2021 goal of identifying methods for improving nuclear test monitoring and verification. In fact, the implemented deep learning denoiser could provide a valuable addition to the existing data processing pipelines.

P3.6-131 – Domain Informed: A Better Approach to Regularization and Semisupervised Learning for Seismic Event Analysis

Author: Lisa Linville[1]
[1]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
Corresponding Author: llinvil@sandia.gov

Typically, data-driven learning works best when we can exploit expectations from our data domain. For example, the development of recurrent neural network architectures to deal with the temporal dependence in language, geometric deep learning for 3-D problems, and physics-constrained Bayesian learning for more interpretable dependencies. Yet it can be unclear how to interject expectations, and which specific expectations will result in better outcomes for a given domain. In seismic event processing, enforcing consistency over disparate observations for an individual event has a long history of empirical value. For example, we almost always use magnitude estimates from many individual stations, drop outliers, and average to arrive at a final event magnitude. Similarly, we can leverage the expectation that stations provide consistent predictions for any event-level attributes, such as event type, when we develop deep learning based predictive models. In this work we show how to formulate this expectation as a loss term during model training and give several examples of how this expectation can result in better model regularization, which can reduce overfitting while still outperforming other methods, give us more trustworthy decision confidence, and allows us to leverage data where no ground truth is available.

P3.6-143 – Application of a Paired Neural Network to Aftershock Identification

Author: Andrea Conley[1]
Co-authors: Brendan Donohoe[1]; Benjamin Greene[1]
[1]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
Corresponding Author: acconle@sandia.gov

Large aftershock sequences cause problems for the International Data Centre (IDC) because the seismic event rate increases dramatically during an aftershock sequence, making correct association of arrivals difficult for the automated pipeline. Aftershock sequences can continue for days or even months after a large earthquake and although aftershocks aren't events of interest for treaty monitoring purposes, they must be reviewed and eliminated by analysts, resulting in delayed release of the IDC bulletins. We turn to machine learning to automatically identify aftershock events and improve automated pipeline performance. In our research, we train a paired neural network (PNN) to automatically perform aftershock identification based on waveform similarity, even when only a few datapoints are available for training. This allows the model to be applied to classes outside of the original training dataset. We analyze the ability of our PNN to classify aftershock data constructed from signals recorded by the IMS network and several open IRIS networks added to real noises from the STanford Earthquake Dataset (STEAD) or the University of Utah network. We apply the trained model and waveform cross-correlation on the constructed test dataset and compare the performance of the two approaches.
Promotional text: This study aligns with the SnT2021 goal of improving nuclear test monitoring and verification. This research aims to provide a method to automatically identify nuisance aftershocks that could potentially be used to improve the IDC automated data processing pipeline.

P3.6-197 – Discrimination Between Earthquakes and Quarry Blasts Using Committee Machine

Author: Ahmed Lethy[1]
Co-authors: Hesham Hussein[1]; Mohamed Gabry[1]; Adel Othman[1]
[1]*National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Egypt*
Corresponding Author: alethy@nriag.sci.eg

In this work, a committee machine was used to combine supervised and unsupervised artificial neural networks to discriminate between Earthquakes and quarries blasts. The unsupervised network is used as a measure of accuracy for the results of the supervised neural network. The unsupervised Self-Organized Map (SOM) and the k-means clustering algorithms are used to estimate support and confidence measures for the results. Meanwhile, the supervised neural network is used to discriminate between Earthquakes and explosions. Using data from the Egyptian National Seismological Network (ENSN). The artificial neural networks are trained using different input parameters which are the P wave spectrum corner frequency (PcF), S wave corner frequency (ScF), and the ratio (Rcf) of PcF to Scf. The combined approach succeeds to discriminate between Earthquakes and quarry blasts in Northern Egypt. The method provides the results with a measure of confidence which eliminates false discrimination.
Promotional text: The current paper represents an idea to implement the artificial intelligent to assist experts in decision-making situations. Committee machine could identify the nature of a particular event using the aid of several discrimination methods.

P3.6-224 – Understanding the Vulnerabilities of Machine Learning Systems in Adversarial Settings

Author: Mohamed Serrhini[1]
[1]*Mohamed First University, Oujda, Morocco*
Corresponding Author: serrhini@mail.ru

Machine learning has advanced radically over the past 10 years, and machine learning algorithms now achieve human-level performance or better on a number of tasks. Machine learning techniques have been extensively deployed for a variety of applications in different areas of life. The success of machine learning algorithms has led to an explosion in demand. Machine learning models are also subject to attacks at both training and testing phases. Attackers can break current machine learning systems, such as by poisoning the data used by the learning algorithm or crafting adversarial examples to directly force models to make erroneous predictions. The main threat during testing is evasion attack, in which the attacker subtly operates by making small perturbations to the test set and modifies input data so that a human observer would perceive the original content but the model generates different outputs. Such inputs, known as adversarial examples, has been used to attack voice interfaces, face-recognition systems, image and video and text-classifiers. This presentation will explain adversarial attacks examples in current machine learning models and its future trends as well as answering what can be done to defend models against adversarial manipulation.
Promotional text: Attacking Real-World Machine Learning Systems, Understand Machine Learning security, Adversial ML, Data poisoning

P3.6-269 – Unsupervised Deep Learning for Identifying Seismic Event Classes in Signal-Rich Records for Environmental Monitoring

Authors: Andreas Köhler[1]; Steffen Maeland[1]
[1]*Norwegian Seismic Array (NORSAR), Kjeller, Norway*
Corresponding Author: andreas.kohler@norsar.no

Manual identification of seismic events in long and signal-rich records is a challenging and timeconsuming task. Power detectors for single stations or array beams are widely just but often provide a vast number of ungrouped events. The need for screening these events arises for example when no a priori information about expected events is available, precise locations cannot be obtained, or location alone is not sufficient for event classification. Unsupervised machine learning allows grouping of seismic signals without using class labels. For our approach, we adapt state-of-the-art, pre-trained convolutional neural networks (CNN) for image recognition. Spectrograms of three-component seismic data are combined as RGB images and fed into the CNN for clustering. The output layer is intuitively visualized to evaluate the obtained grouping. We test two different approaches: grouping pre-detected events and sliding window processing combing the detection and clustering step. We apply the methods to typical data sets in environmental seismology: seismic data recorded at glaciers in Svalbard (icequakes) and at an unstable rock slope in Southern Norway. In both cases, expert-labeled events are available to evaluate the results. We find the unsupervised deep neural network to be a powerful tool to analyze and differentiate between the seismic events.

Promotional text: We present a method for automatic identification of seismic events using machine learning and its application for environmental monitoring. Our contribution addresses the need for new verification technologies as well as issues in a global context such as climate change.

P3.6-326 – A Neural Network Architecture for Detecting Repeating Events Using Seismic Arrays

Authors: Steffen Maeland[1]; Andreas Köhler[1]; Ben Dando[1]
[1]*Norwegian Seismic Array (NORSAR), Kjeller, Norway*
Corresponding Author: steffen@norsar.no

Recent advances in convolutional neural networks (CNNs) have brought impressive detection capabilities to one- and three-component seismic stations. Still, the highest sensitivity to repeating events is obtained by beamforming signals over a seismic array. We propose a new neural network architecture that combines the two, by introducing a two-dimensional convolutional layer that encodes the propagation time delays between array stations. This results in a purely empirical model, which does not rely on the plane-wave approximation of traditional beamforming. We demonstrate the model by detecting and classifying repeating blasts from multiple mining sites in northern Fennoscandia. Results are compared to those obtained by empirical matched field processing, a highly sensitive method which, similarly, does not require signals to be coherent under the plane-wave model.

Promotional text: We present a machine learning method for seismic arrays, which aims to improve verification capabilities through higher detection sensitivity and better identification of repeating sources.

P3.6-428 – The Optimised Local Renyi Entropy-Based Shrinkage Algorithm for Sparse Time–Frequency Distribution Reconstruction

Author: Victor Sucic[1]
Co-authors: Vedran Jurdana[1]; Ivan Volaric[1]; Götz Bokelmann[2]; Ronan Le Bras[3]
[1]*University of Rijeka, Croatia*
[2]*University of Vienna, Austria*
[3]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: v.sucic@gmail.com

Time-frequency distributions (TFDs) are useful tools for nonstationary signals analysis. Due to the presence of unwanted cross-terms, useful information extraction from TFDs has proven to be a challenging task, in particular when analysing noisy real-life signals. One way to suppress the cross-terms is by employing compressive sensing methods that enforce sparsity in the resulting TFD. In this work, we have developed a sparse algorithm that reconstructs a TFD from a small sub-set of signal samples in the ambiguity domain. The algorithm utilises the information from both the short-term and the narrow-band Renyi time-frequency entropies, while its parameters are optimised using evolutionary meta-heuristic methods. Results are presented for synthetic and real-life signals in noise, and compared to the state-of-the-art sparse reconstruction algorithms.

Promotional text: We have proposed a novel algorithm for sparse representation of nonstationary signals. The algorithm utilises Renyi time-frequency entropy information, and it's optimised using evolutionary methods.

P3.6-439 – Artificial Intelligence/Machine Learning Vision Technology Application to OSI Search Logic Support

Authors: Pengda Wang[1]; Peng Li[2]; Bo Zhao[1]; Jingshi Su[1]; Yixuan Cao[3]
[1]*Diankeyun (Beijing) Technology Co., Ltd., China*
[2]*Hope Investment Development Corp. Ltd., Beijing, China*
[3]*Hope Investment Development Corp. Ltd., Beijing, China*
Corresponding Author: lipeng1406@163.com

Advancements in AI/ML are creating a paradigm shift in virtually every sector of the tech industry. Among the endless applications, AI vision technology based on Deep Neural Network, finds its strength at image processing, pattern recognition and image interpretation, which can be utilized for manufacturing, medical diagnosis, and OSI. Current OSI search logic relies on finding and identifying nuclear test signatures and anomalies by means of inspectors' visual observation and test results of OSI equipment. Normally visual observation could be the first breakthrough to initiate the OSI search logic. OSI visual observation is based on nuclear experts' scientific knowledge of nuclear tests experience. Judgement bias exists as a result of inspector individual difference and human errors. For this case, AI vision could be utilized as supporting strength to assist OSI operations. This work would carry out the preliminary study over the principles of AI vision technology's potential application to OSI mission support. It would also identify the advantages and possible disadvantages of AI/ML for OSI application. For example, AI vision is relied on large amount of data base for model training, this would cause the concern of keeping the balance of OSI operation efficiency and intrusiveness.

Promotional text: This work carried out a preliminary study of AI/ML vision technology application to OSI search logic supporting.

P3.6-509 – Analysing Radioxenon Spectra with Machine Learning Algorithms to Predict Activity Concentration of Each Isotope

Author: Sepideh A. Azimi[1]
Co-authors: Hossein Afarideh[1]; Martin B. Kalinowski[2]; Abdelhakim Gheddou[2]
[1]*Amirkabir University of Technology (AUT), Tehran, Iran*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: azimi.bme@gmail.com

In this study, we aim to develop a new approach using machine learning and data mining algorithms to estimate the activity concentration of radioxenon isotopes of any unknown sample without extensive mathematical calculations from calibrated raw spectra. So far, several methods have been applied such as the region-of-interest (ROI) and the simultaneous decomposition analysis tool (SDAT) to estimate net counts for each isotope. By means of machine learning methods, we specifically analyze Beta–Gamma coincidence spectra without the availability of processing parameters that are currently used by the CTBTO such as successive subtractions of background interferences (i.e., radon and its daughters), which can reduce errors and human workload of analysis. Thus, our purpose is to improve MDC in the detection of low-level activity concentration of radioxenon isotopes.
Promotional text: Machine learning for 2D radioxenon beta-gamma coincidence raw radioxenon spectra analysis.

P3.6-516 – Automatic Radionuclide Detection Using Deep Neural Networks

Author: Rezky Mahardika Saryadi[1]
Co-author: Sri Sundari Retnoasih[1]
[1]*Indonesia National Nuclear Energy Agency (BATAN), Indonesia*
Corresponding Author: rezkymahardika@batan.go.id

One of the implementations to support the CTBT instrument measurement is radionuclide identification. An automatic real-time identification radionuclide can be an option for some applications, including monitoring of environmental contamination and prevention of nuclear terrorism. This research is about the automatic algorithms that provide feedback about the presence of any radiations anomaly. In addition to designing better hardware, a sophisticated computer algorithm is also a needed for automatic detection of radioactive materials by developing a method for supervised learning model from identified gamma spectrum using deep learning. The gamma-ray detector data for this study was obtained from public data from ORNL for research and development purposes. For the simulations, OpenMC and Geant4 is used to generate data files in a time-series manner and modeling standard NaI(Tl) detector resolution at 661keV. The data set contains six different types of source combinations: High enriched uranium (HEU), Cesium 137, Iodine 131, Cobalt 60, Technetium, and LEU, in total 10000 data files with ground truth were provided in the dataset. Experiments on simulated spectra suggest that deep learning methods (RNN + LSTM) can achieve a higher F1 score at difficult testing conditions compared to the best performing traditional machine learning models, obtaining a 91.11% score during evaluation.
Promotional text: This research can be used for radionuclides identification in any various fields, including in the difficult areas. Besides, it also can be used for environmental monitoring system. By doing this research, the author also might open any collaborations from another participants.

P3.6-541 – Research on Local Event Detection Method Based on Deep Convolutional Neural Network

Author: Jian Li[1]
[1]*CTBT Beijing National Data Center, Beijing, China*
Corresponding Author: li.jian@ndc.org.cn

An event detection method based on deep neural network combined with the average wave speed ratio of multiple stations is proposed for detecting local events under the global sparse

seismic network. Firstly, the method uses multi-task convolution neural network to detect and identify the direct P and S phases, as well as estimate their arrival time. Then a joint network of GAN and LSTM is used to identify and eliminate the noise signals in detections. Finally, according to the principle that the P and S wave velocity ratios of local earthquakes in the regional network are consistent, the association of seismic phases from multiple stations are realized. The P and S phases arrival time and wave velocity ratio are used to estimate the preliminary origin time. The hyperbolic method based on station pairs is used to estimate the preliminary event location. Using the preliminary origin time and location of the event as the initial value of the conventional iterative inversion location method, and finally the exact event location and time are obtained.

Promotional text: This paper proposed a local event detection method based on the deep convolution neural network. The test results verify the effectiveness of the deep learning method in seismic monitoring data processing.

P3.6-615 – On Using Self-Sustained Events for Stochastic Waveform Modelling with Deep Neural Networks

Authors: Christophe Millet[1]; Xavier Cassagnou[2]; Mathilde Mougeot[2]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[2]*Ecole Nationale Superieure (ENS) Paris-Saclay, France*
Corresponding Author: xavier.cassagnou@ens-paris-saclay.fr

The International Monitoring System (IMS) includes waveform sensor stations connected to a centralized processing system in the International Data Center (IDC) in Vienna. While the performance of the IMS is known to be related to atmospheric properties, the usual approach at the IDC still relies on expert judgments and simple models to incorporate the environmental knowledge. In this work, we develop a deep neural network (NN) that takes advantage of basic physical laws to learn a model for the stochastic component involved in wave propagation, and predict some statistics of the recorded time series. A neural network architecture is proposed which uses additional layers to embed some properties on the stochastic parameterization used to represent the atmospheric randomness, given appropriate context information on the medium (mean, standard deviation, ...). The NN model is trained on data emanating from individual stations of the IMS, using far-field self-sustained natural events such as microbaroms and high-fidelity simulation data. Finally, it is shown how this neural network architecture can be used in combination with probabilistic Bayesian models to improve network processing (detection, association) as well as our understanding of atmospheric variability.

Promotional text: We develop a new generation of deep neural network that takes advantage of basic universal laws to predict the background infrasound noise. In combination with Bayesian approaches such as NET-VISA, we believe that the neural network can enhance the association process.

P3.6-622 – On Filtering Regional Turbulence Noise in Infrasound Data with Interpretable Neural Networks

Authors: Cyril Nefzaoui Blanchard[1]; Christophe Millet[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: cyril.blanchard@cea.fr

The environment of infrasound stations is characterized by mesoscale wind speed and temperature fluctuations that affect the temporal variability of the Atmospheric Boundary Layer (ABL). While the statistical characteristics of turbulence are poorly constrained, modeling such statistics appears to be crucial since each sensor of infrasound stations is subject to this local noise that may mask true signals and cause false detections. In this work, we propose to improve the station processing by characterizing the noise due to turbulence in the ABL using neural networks. Assuming that the turbulence is

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

governed by a parametric nonlinear dynamical system which involves known dimensionless numbers, a neural network architecture is proposed to infer the turbulent noise in the data. For this task, we design a custom deep autoencoder network to obtain a coordinate transformation into a reduced space where the dynamics of the ABL can be sparsely represented. The resulting modeling framework combines the strengths of deep neural networks for flexible representation and sparse identification of nonlinear dynamics for parsimonious models. The performance of our approach is assessed using real-world signals recorded at several infrasound stations of the International Monitoring System, over days and nights, and for different seasons.

Promotional text: We introduce a new strategy to reduce the wind noise in the recorded signals of the IMS stations. This strategy is based on using machine learning to extract turbulence noise from data than can be translated into knowledge about the underlying fluid mechanics.

P3.6-651 – Simulation of Operational Results of NET-VISA on a Three-Month Historical Data Set

Author: Ronan Le Bras[1]
Co-authors: Noriyuki Kushida[1]; Pavel Strachota[1]; Nimar Arora[2]; Geeta Arora[2]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Bayesian Logic, Inc., CA, USA*
Corresponding Author: ronan.lebras@ctbto.org

NET-VISA has benefitted tremendously from the interaction between its developers and CTBT State Signatories experts. One way that this interaction has taken place is through the delivery of data sets processed with successively enhanced versions of the software, with feedback from the experts. We present the results of a full simulation of operational results conducted offline with a recent version of NET-VISA (December 2020). The processing includes the complete three-pipeline configuration. The data set covers August-October 2016, includes an announced nuclear test, and is intended to be delivered to the State Signatories experts. The analysis will cover the essential comparison criteria of overlap and inconsistency between the automatic results and reviewed results, but will also go deeper into the comparison of the NET-VISA results with the SEL3 automatic bulletin for that period, taking into account location accuracy and completeness of the automatic events.

Promotional text: The physics-based Machine Learning operational software NET-VISA is being continuously improved. We present the most recent offline results on a three-month historical data set to be distributed to State Signatories.

P3.6-703 – Global Scale Discrimination of Explosions and Earthquakes with Deep Learning

Authors: Rayna Arora[1]; Nimar Arora[2]
Co-author: Ronan Le Bras[3]
[1]*CTBTO Youth Group*
[2]*Bayesian Logic, Inc., CA, USA*
[3]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: rayna.aro@gmail.com

Discriminating between explosions and earthquakes is necessary for building hazard maps and monitoring applications. Previous studies have used classical ML techniques based on the amplitudes of various phases. More recent methods based on Deep Learning use the full seismic waveform; however, they rely on detections made by nearby stations. These methods are inapplicable for global-scale networks such as those maintained by the International Monitoring System (IMS). In our work, we perform a study using seismic waveforms of explosions and earthquakes as classified by the International Seismological Center (ISC) for events detected by the International Data Center (IDC). We show a comparison of various Deep Learning techniques on this task and our experiments demonstrate that the discrimination capabilities for events with magnitude between 3-4 mb degrade smoothly with distance between the event and the nearest station.

Promotional text: We present a study of Deep Learning applied to the explosions/earthquakes discrimination problem at a global scale.

P3.6-706 – BazNet: A Deep Neural Network for Confident Three-Component Back Azimuth Prediction

Authors: Joshua Dickey[1]; Geeta Arora[2]; Nimar Arora[2]; Megan Slinkard[3]; Noriyuki Kushida[3]; Ronan Le Bras[3]
[1]*Air Force Technical Applications Center (AFTAC), FL, USA*
[2]*Bayesian Logic, Inc., CA, USA*
[3]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: joshuadickey@gmail.com

Three-component stations traditionally rely on polarization analysis to estimate the back azimuth of each arriving wave. Unfortunately, these polarization estimates suffer from both high error and low confidence, and contribute very little to the downstream association algorithms at the IDC. Here, we present BazNet, a deep neural-network-based back azimuth predictor for three-component stations. For existing stations with ample historical training data, the technique achieves an overall median absolute error of around 14°, a modest improvement over polarization. More importantly, each estimate is accompanied by a robust certainty measure, which is highly covariant with the error. By integrating the BazNet predictions and certainties into NETVISA, we demonstrate the potential of this algorithm to enhance global association at the IDC.

Promotional text: This work explores the use of a temporal convolutional neural network architecture for improved three-component back azimuth estimation, potentially enhancing the seismic signal processing pipeline used at the IDC for nuclear test monitoring and verification.

P3.6-707 – ArrNet: A Deep Neural Network for Confident Arrival Time Estimation

Authors: Raul Pena[1]; Joshua Dickey[1]
[1]*U.S. Air Force Technical Applications Center (AFTAC), FL, USA*
Corresponding Author: raulpena7@gmail.com

Phase arrival time estimation for tele-seismic signals is a critical and fundamental step in the detection and localization of nuclear explosions and seismic study in general. Typically, this process involves heavy human interaction with more than half of all automatically detected arrivals being manually re-timed by a human analyst. Developments in Artificial Intelligence and specifically in the field of Deep Learning have produced architectures capable of tackling this task to minimize human involvement and improve the overall data processing pipeline. To this end, we introduce ArrNet, a deep Temporal convolutional Network (TCN) capable of reducing the mean residuals from automatic processing by more than 50%. ArrNet has been trained to be transportable by including data from all available IDC stations. It is capable of providing accurate arrival time estimates for any new station and across a wide range of signal to noise ratios. Additionally, ArrNet has been trained to produce measurements for the 94%, 80% and 50% confidence intervals by implementing quantile loss functions in addition to regressing the arrival time estimate. These margins are covariant with the observed errors and work as a confidence metric for the estimated arrival time in order to refine downstream location and association estimates.

Promotional text: This work explores the use of a temporal convolutional neural network architecture for improved three-component arrival time estimation, potentially enhancing the seismic signal processing pipeline used at the IDC for nuclear test monitoring and verification.

6.4. Theme 4: Performance Evaluation and Optimization

The operation and sustainment of a global network of monitoring systems poses substantial challenges. Near real time acquisition and forwarding of continuous and segmented data from the IMS and the subsequent processing and analysis of data at the IDC also present great challenges. Strict requirements for operational data availability, quality and timeliness must be met and sustained. The results of processing and analysis raise further issues with regard to quality and timeliness. The handling of OSI data is also subject to specific requirements outlined in the Treaty and the OSI Operational Manual. In addition, the performance of the IMS and IDC depends on enabling technologies such as information technology and power systems.

Beyond the IMS, IDC and OSI, the full Treaty verification system also includes NDCs and the possible use of other data to supplement IMS data for expert technical analysis. NDCs provide advice to their national authorities that make decisions within a broader policy context. NDCs may have IMS data and Treaty monitoring functions integrated into national operations and procedures to enhance their performance. NDCs provide feedback to the IDC on its products and services, including the NDC analysis tools, and conduct preparedness exercises jointly with other NDCs.

Evaluation and optimization of the performance of the CTBT verification system involves other factors such as improvements to efficiency and cost effectiveness, reliability and security. Contributions on improving performance related to the verification system are encouraged.

2020 brought about unprecedented challenges for the monitoring system with the onset of the COVID-19 pandemic. Facing these challenges, the system demonstrated resilience while remaining functional, thus providing the organization and stakeholders with important lessons that will be useful in the future.

T4.1 Performance Evaluation and Modelling of the Full Verification System and Its Components

Highlights

O4.1-213 described the efforts of the metrology community to improve the measurement standards that underpin data quality in CTBT monitoring activities. This aims to foster greater contact with relevant stakeholders, with the objective of establishing primary measurement standards that are currently lacking for CTBT waveform technologies to provide traceability to low frequency phenomena across the fields of airborne and underwater acoustics, and vibration (seismology). The presentation introduced Infra-AUV, an EU project that will develop high precision, laboratory based calibration methods as well as methods suitable for field use. Infra-AUV will also address requirements for reference sensors that link laboratory calibration capabilities to field requirements for measurement traceability.

Calibrations and quality control aspects were also addressed in presentations P4.1-336, P4.1-159 and P4.1-196. P4.1-336 described a system that expands the existing tools at Wilson Alaska Technical Center (USA) and generates comprehensive network intelligence that informs upstream quality assurance efforts. The presentation demonstrated network performance over almost a year of metrics. P4.1-159 presented a tool that extends the standard station interface (SSI) for intuitive execution of instrumental calibrations and review of calibration results. The module has been deployed at a number of stations. The poster focused on the functionalities supporting station operators during calibration activities. P4.1-196 described how the beta endpoint is used in combination with the 662 keV gamma peak to track the gain drift in the system before and after a sample measurement to ensure system stability during the count. By introducing another isotope to the currently used ^{133}Cs check source, ^{133}Ba would provide improved gain and efficiency monitoring, and potential data on detector degradation.

P4.1-330 and P4.1-455 discussed aspects of data processing in relation to IDC performance. P4.1-330 compared the performance of NET-VISA with the current operational approach (global association) with minimum detectability maps for simulated explosions. P4.1-455 discussed the tuning of the IMS seismic stations by optimizing their detection thresholds. Two principal performance measures are the rate of automatic detections associated with events in the REB and the rate of detections manually added to the REB (miss rate). These two metrics are significantly influenced by pre-specified slowness, frequency and azimuth-dependent detection thresholds used in the short term average over long term average ratio detection scheme. The thresholds should be set at optimal values that minimize the miss rate but maintain high precision.

P4.1-324 presented the status of the IDC SHI Reengineering project, currently in the implementation phase and under active development. It notes that the first alpha tester group concluded the test of the web service and highlighted the challenges and technical solutions to provide and monitor test instances to users around the world using cloud technologies.

P4.1-113 stressed the need to update the user guide on IDC processing of SHI data (written in 2002) and presented the platform made available as an NDC Forum topic, to take advantage of the considerable collective technical expertise of NDC staff and collect feedback.

P4.1-294 presented the results of testing at the Australian NDC of the NDC in a box release containing the NET-VISA associator integrated with SeisComP3. It describes the integration of non-IMS stations within NDC in a box to examine if performance improved in areas of interest to the NDC.

In relation to ATM, two studies were dedicated to assessing the importance of high input resolution. P4.1-593 presented a methodology developed to run hundreds to thousands of paired ATM (FLEXPART) simulations in which only the resolution is varied, evaluating metrics such as plume arrival time and concentration. The method has been used to explore paired FLEXPART simulations driven by 0.5 versus 1.0 degree ECMWF and Global Forecast System (GFS) meteorological input every 36 hours over periods of 8 to 12 months. P4.1-595 presented an investigation at the IDC on utilizing high resolution ATM to locate possible source regions after detections of radioactive substances, using ATM backward simulations and comparison with data from the IMS noble gas system at RN33 (Germany).

Based on recent developments in metamodelling, an innovative approach to compute source characteristics of infrasound events was presented in O4.1-624. Localizing infrasound events is done by combining the usual Bayesian inference, which provides the posterior probability density function (PDF), with carrying out sampling over a metamodel built from an experimental design of limited size to update the posterior PDF. The method can compute source characteristics from signals recorded at several IMS stations at a low numerical computation cost. Such a metamodel is more efficient than the stochastic models used in the Bayesian Infrasound Source Location (BISL) approach, and it is better suited for real time monitoring.

O4.1-519 introduced a fully automated stochastic method for calculating the optimal station distribution inside a permanent/

temporary seismic network, to locate seismic events more accurately, using a fuzzy self-tuned particle-swarm-optimization technique that can carry out a complete search of the entire area inside the network. The method was evaluated using a data set of 1562 earthquakes in the Iran region. The results show that the accuracy of relocated events could be increased up to 15 per cent with respect to the HYPO71 program.

P4.1-248 presented the agreement between the CTBTO and the Government of Italy on the participation of the seismic station in Cludinico as a prototype Cooperating National Facility in experiments conducted by the Commission. It illustrated the technical details of the solutions adopted to incorporate the station into the IMS network.

The importance of using various data sets to assess the performance of the IMS system was emphasized in P4.1-339 and P4.1-446. P4.1-339 showed recordings of events linked to controlled underwater explosions of World War II ordnance in 2020. These relatively small explosions can be used to assess location accuracy and the estimated magnitude of events recorded by the IMS network. P4.1-446 analysed statistics of mostly natural seismicity waveform events processed and analysed over the past 20 years at the IDC, as the network grew in size and became established. It analysed multiple parameters including magnitude for events detected by seismic, hydroacoustic and infrasound stations.

Exercising the verification system as a whole represents a unique scientific opportunity and method for improving nuclear test monitoring and verification. O4.1-121 introduced the Radiation Field Training Simulator (RaFTS), an innovative signal injection methodology. Originally developed for radiation detectors such as IMS radionuclide/noble gas sensors, it can be extended to other IMS technologies by injecting signals reflecting the complexity of a nuclear explosion, thus allowing enhanced training and continual monitoring of performance.

NPEs are a major opportunity for NDCs to conduct exercises based on a scenario investigation for the detection of nuclear explosions in the framework of CTBT monitoring. O4.1-636 detailed the scenario of the NPE in 2019. Two NDCs presented their investigations in P4.1-365 and P4.1-613. The NPE scenario consisted of the announcement by a fictitious State of a reactor incident with a release of unspecified radionuclides into the atmosphere. The incident was questioned, and in a later stage regional seismic data was added, which contained an anomaly pointing to an explosive event. An Exercise Expert Technical Analysis was requested from the IDC for the first time. As part of the NPE process, NDCs discuss the results of the exercise, and lessons learned are used for future NPEs. The NPE 2019 process was delayed due to the postponement of in person meetings of NDCs in 2020 and 2021.

O4.1 Performance Evaluation and Modelling of the Full Verification System and Its Components Abstracts of Oral Presentations

O4.1-121 – Signal Injection as a Means to Exercise the Entire CTBT Monitoring Regime

Author: Steven Kreek[1]
Co-authors: Dan Bower[1]; Dave Trombino[1]; Bill Dunlop[1]; Eric Swanberg[1]; Greg White[1]; Josh Oakgrove[1]; Philip Dunn[2]; Steven Pike[2]
[1]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
[2]*Argon Electronics Ltd, Luton, United Kingdom*
Corresponding Author: kreek1@llnl.gov

A nuclear explosion results in a complex combination of signals including radioactivity released to the environment, seismic, infrasound, and hydroacoustic. The International Monitoring System (IMS) was established to detect these signals and analysts around the world train in the interpretation of them. However, the unique combination of signals indicative of a nuclear explosion is only fully replicated in the IMS by an actual nuclear explosion, which is a rare event. While analysts can train with synthetic data, exercising the operational IMS hardware and process was impractical until a signal injection methodology called RaFTS (Radiation Field Training Simulator) was demonstrated by Lawrence Livermore National Laboratory. Developed for radiation detectors such as those in IMS radionuclide/noble gas (RN/NG) stations, RaFTS injects pulses directly into operational detectors which are then interpreted through their electronics in the same way as real signals. Because of the universality of the RaFTS signal injection approach, it could also work with other IMS detector types, including seismic, infrasound, and hydroacoustic, thereby enabling a system-wide exercise of all IMS operating components. This presentation describes the proposed approach to enhance training and operationally exercise the entire regime. RaFTS was recently licensed for commercialization to Argon Electronics (UK) Ltd.

Promotional text: Exercising the system represents a unique scientific opportunity and method for improving nuclear test monitoring and verification in a systems manner, including modeling/simulation of representative signatures, to their detection and interpretation.

O4.1-213 – Metrology for Low-Frequency Sound and Vibration: An Introduction to the Infra-AUV Project

Author: Thomas Bruns[1]
Co-authors: Christian Koch[1]; Dominique Rodrigues[2]; Stephen Robinson[3]; Lars Ceranna[4]; Jacob Winter[5]; Franck Larsonnier[6]; Richard Barham[7]
[1]*Physikalisch-Technische Bundesanstalt, Berlin, Germany*
[2]*Laboratoire national de métrologie et d'essais, France*
[3]*National Physical Laboratory (NPL), Teddington, United Kingdom*
[4]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
[5]*Hottinger Brüel & Kjaer, Darmstadt, Germany*
[6]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[7]*Acoustic Sensor Networks Limited, United Kingdom*
Corresponding Author: thomas.bruns@ptb.de

Infra-AUV is a new EU project that will establish primary measurements standards for low frequency phenomena across the fields of airborne and underwater acoustics and vibration (seismology). Combining expertise from the national measurement institutes and geophysical monitoring station operators, it will develop both high-precision laboratory-based methods of calibration and methods suitable for field use. Infra-AUV will also address requirements for reference sensors that link laboratory calibration capabilities to field requirements for measurement traceability. To establish standards in the three technical areas, a variety of calibration principles will be employed, including extension of existing techniques such as reciprocity and optical interferometry, and development of new methods. There will also be an investigation of the potential for in-situ calibration methods, including use of both artificially generated and naturally occurring stimuli such as microseisms and microbaroms. The influence of calibration uncertainties on the determination of the measurands required by the monitoring networks will also be studied. The project was strongly motivated by the CTBTO strategy to drive new metrology capability to underpin IMS data. The intention is to maintain interaction with stakeholders, not only in connection with the IMS, but with the broad range of users of low frequency acoustic and vibration data.

Promotional text: Our contribution describes how the metrology community is coming together to improve measurement standards that underpins data quality in CTBT monitoring activities, and aims to foster greater contact with relevant stakeholders.

O4.1-519 – Seismic Network Geometry Optimization Using a Fully Automated Stochastic Method

Authors: Saeed Soltani Moghadam[1]; Gholam Javan Doloei[1]
[1]*International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran*
Corresponding Author: saeed.sltm@gmail.com

One of the most important goals of any seismic network, is the ability to locate more accurately seismic events. Accordingly, accurate stations distribution, plays an important role for achieving that goal. In this study, we present a fully automated stochastic method for calculating the optimal station distribution inside a permanent/temporary seismic network. Using fuzzy self-tuned particle swarm-optimization technique, we can do a complete search on the entire area inside the network to find the best plausible station coordinates by generating synthesized earthquakes and relocating them in a forward-inverse manner. The new stations distribution could be completely far (designing a new network) or relatively close to the current seismic network (optimizing current network). In either cases the final network pattern represents increases the accuracy of the relocated events. We evaluated the proposed method on a data-set comprising 1562 earthquakes in Iran region (recorded by Iranian-broadband-seismic-network (BIN)) with magnitudes Mw>4.0, during 2010-2020. The maximum displacement of 25 km for each station from its initial location was considered, then the program starts to find the best coordinates. The final results showed that using the optimized seismic network, the accuracy of relocated events (based on the Hypo71 event-accuracy criteria) could be increased up to 15%.

Promotional text: Increasing the accuracy (efficiency) of seismic events (networks) has always been one of the most important goal of the CTBTO in a broad context. Here we present a fully automated stochastic-method for calculating the optimal stations distribution inside a seismic network.

O4.1-624 – Bayesian Localization of Infrasound Events with Propagation Metamodels

Authors: Christophe Millet[1]; Julien Vergoz[1]; Alexandre Goupy[1]; Didier Lucor[2]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
[2]*Laboratoire d'Informatique pour la Mécanique et les Sciences de l'Ingénieur, France*
Corresponding Author: christophe.millet@cea.fr

Infrasound has proven to be useful for localizing events, especially in the context of the CTBT. Among the usual approaches, the Bayesian inference is often favored as it provides the posterior probability density function (PDF) for source parameters. In these methodologies, propagation models are constructed by numerically propagating signals through a set of plausible atmospheric specifications so as to obtain distributions for arrival characteristics. These approaches, however, drastically increases the number of model runs and for this reason, automatic network processing is often based either on simplified stochastic models or generative models. Such models, however, do not include the current atmospheric specifications and additional analysis is often necessary to better refine the source location estimate. In this work, we combine the Bayesian framework and recent developments in metamodeling to update the posterior PDF describing the source localization. The main difference with

the standard Monte Carlo method lies in the fact that the sampling is carried out over the metamodel, which is built from an experimental design of limited size. This makes such propagation metamodels more efficient than their stochastic counterparts and better suited for real-time monitoring. The performance of the method is demonstrated through reanalyzing several recent events.
Promotional text: In this work, localization is obtained using a metamodel which offers a way to compute source characteristics at a low numerical cost from the signals recorded at several IMS stations. Such a metamodel is more efficient than the stochastic models used in the BISL approach.

O4.1-636 – National Data Centre Preparedness Exercise (NPE) 2019 – Scenario Design and Expert Technical Analysis

Authors: J. Ole Ross[1]; Giuseppe Ottaviano[2]; Antonietta Rizzo[2]; Peter Gaebler[1]; Nicolai Johannes Gestermann[1]; Lars Ceranna[1]
[1]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
[2]*Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Italy*
Corresponding Author: ole.ross@bgr.de

NDC Preparedness Exercises (NPE) are an opportunity to practice the verification procedures for the detection of nuclear explosions in the framework of CTBT monitoring. The NPE 2019 scenario was developed in close cooperation between the Italian NDC-RN (ENEA) and the German NDC (BGR). The fictitious state RAETIA announced a reactor incident with release of unspecified radionuclides into the atmosphere. Simulated concentrations of particulate and noble gas isotopes at IMS stations were given to the participants. The task was to check the consistency with the announcement and to search for waveform events in the potential source region of the radioisotopes. During NPE2019 an Exercise Expert Technical Analysis was requested from the IDC for the first time. A fictitious state party provided within the scenario (simulated) national measurements of radionuclides and asked for assistance in analysing the additional samples. Especially backward ATM and the search for seismic events in the possible source region was requested. In addition the overall consistency to a scenario event, a reactor incident declared by the ficititious state Raetia was questioned. In the third and last stage of the exercise, national regional seismic data were distributed among the participants which contained a anomaly pointing on a explosive event.
Promotional text: NPE feature monitoring expertise with scenarios of partially simulated CTBT relevant events. Highlights of NPE 2019: integration of multiple RN sources, ETA request, and synthetically manipulated seismic data.

P4.1 Performance Evaluation and Modelling of the Full Verification System and Its Components Abstracts of Poster Presentations

P4.1-113 – Updating the "IDC Processing of SHI Data" User Guide

Author: Christopher Young[1]
Co-author: Christos Saragiotis[2]
[1]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: cjyoung@sandia.gov

National Data Centre (NDC) staff need to interpret International Data Centre (IDC) seismic, hydroacoustic, and infrasonic (SHI) data processing results, which requires detailed knowledge of IDC SHI data processing. Similar understanding is needed by those that want to propose new IDC SHI data processing algorithms. To find the required information, NDC staff access the "IDC Processing of SHI Data" document, a comprehensive, detailed and accurate (at the time when it was written in 2002) user guide. Unfortunately, this document is currently outdated as many techniques recently adopted by the IDC are not described in it. Furthermore, not all

technologies and techniques are described at the same depth and there are some inevitable errata. To significantly update this lengthy user guide and maintain the high overall quality is no trivial endeavor. Hence, in January 2019 a platform to note problems with the document and propose fixes was made available as an NDC Forum Topic, to take advantage of the considerable collective technical expertise of the NDC staffs. In this presentation we will provide an introduction to the platform, review results that have been entered so far, and discuss the path forward to producing an updated version of the document.
Promotional text: This presentation supports the conference goal to identify opportunities and methods for improving nuclear test monitoring and verification. Our NDC Forum platform allows States Parties experts to assist the IDC by noting issues with the IDC waveform data processing document.

P4.1-159 – The SSI Calibration Module

Authors: Yacine Sid Ahmed[1]; Moctar Moumouni Kountche[1]; Benoit Doury[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: yacine.sid.ahmed@ctbto.org

The SSI calibration module is a tool that extends the Standard Station Interface (SSI) for intuitive execution of instrumental calibrations and review of calibration results. It aims to support the complex planning, technical execution, evaluation and reporting of the calibration of IMS seismic and T-phase stations. The SSI calibration module also provides a single and standard interface that masks the heterogeneity of the hardware/software used at different IMS stations. Finally, the SSI calibration module helps to standardize the communication through the full implementation of IMS2.0 format to dramatically ease the exchange, parsing and review of calibration messages, for both the Station Operator and PTS staff. The module has been deployed at a number of stations and the PTS currently continues its deployment at other stations. This poster presents the SSI calibration module and focuses on the functionalities supporting Station Operators during calibration activities.

P4.1-196 – Combined Quality Control Check Source for Improved Gain Tracking and Calibration

Author: Johnathan Slack[1]
Co-authors: Michael Mayer[1]; Matthew Cooper[1]; James Ely[1]; Michael Foxe[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: johnathan.slack@pnnl.gov

Quality control (QC) in beta-gamma coincidence systems that are used for radioxenon measurement is currently performed using a Cs-137 check source. Compton scattering in the scintillating plastic (polyvinyl-toluene) of the beta detector creates a line of activity from the 667 keV gamma captured by the sodium iodide (NaI) across the beta dynamic range. Fitting the Compton scatter line provides a beta endpoint energy. The beta endpoint is used in combination with the 662 keV gamma peak to track the gain drift in the system before and after a sample measurement to ensure system stability during the count. Periodic QC checks are performed as well to monitor the long-term health of the system. By introducing another isotope to the check source, Ba-133, a second Compton scatter line can be generated in the coincidence counts that is well separated from the first. This would provide improved gain tracking, efficiency monitoring, and potential data on detector degradation. The multiple low-energy gamma lines of Ba-133, as compared to the 662 keV of Cs-137, would provide additional peaks for the energy and efficiency calibrations.
Promotional text: This presentation provides a new method for improving the reliability and accuracy of nuclear test monitoring systems.

P4.1-248 – The Italian CTBTO CNF: Readiness Status

Authors: Damiano Pesaresi[1]; Michele Bertoni[1]; Elvio Del Negro[1]; Paolo Comelli[1]; Stefano Parolai[1]; Nicola Casagli[1]
[1]*Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Sgonico, Italy*
Corresponding Author: dpesaresi@inogs.it

The CTBTO PrepCom and the Government of Italy agreed that the seismic station located in Cludinico (CLUD) may participate as a prototype Cooperating National Facility (CNF) in experiment conducted by the Commission. The Government of Italy designed the National Institute of Oceanography and Applied Geophysics – OGS (Italy) as responsible for the management of the station. This station can contribute to further refine the CTBTO location capabilities in the Europe/Middle East area of about 21% as shown in Pesaresi and Horn (2015). In this presentation, we will illustrate the technical details of the solutions adopted to incorporate the Italian CNF into the CTBTO International Monitoring System (IMS). We considered a CTBTO specific seismic data acquisition system, but we then opted to keep the available standard one with the addition of the CTBTO Standard Station Interface (SSI). For the SSI we had to go through hardware and software procurement: we then experienced some difficulties in installing the SSI software and its required Operating System, solved with the help of the PTS. We will also illustrate the other required technicalities like the upgrade of the U.S. the anti-tamper device operations, the establishment of data communication link and the security measures adopted.

Promotional text: The CTBT verification system includes the possible use of other data for expert technical analysis. PrepCom and Italy agreed to designate OGS seismic station CLUD as a CNF. This can contribute to refine CTBTO locations in the Europe/Middle East of about 21%.

P4.1-294 – Australian NDC Testing of the NET-VISA Application Integrated with SeisComP3

Authors: Spiro Spiliopoulos[1]; Svetlana Nikolova[1]
[1]*Geoscience Australia, Canberra, Australia*
Corresponding Authors: spiro.spiliopoulos@ga.gov.au, sbnikolova@yahoo.com

The results of testing, at the Australian NDC, of the NDC-in-a-Box (NIAB) release containing the NET-VISA associator integrated with SeisComp3 (SC3) are presented. The aim of this work was twofold: First to test how well the NIAB release was able to reproduce the VSEL3 bulletin produced by the International Data Centre (IDC) using data from the IMS network of stations. Second, to use an updated version of the NET-VISA software that allowed integration of non-IMS stations within NIAB to examine if performance improved in areas of interest to the NDC. In both cases the scdfx detector was used. Testing showed that the NIAB release emulated the VSEL3 bulletin to a satisfactory extent. The improvement in monitoring threshold gained using NET-VISA integrated with non-IMS stations is reported for the Australian and another region. In Australia the earthquake catalogue was the ground-truth to test the performance of the automatically generated NET-VISA bulletin. The automatic bulletin from NIAB contained a similar number of earthquakes to the Australian catalogue and the automatic events had locations within 2 degrees of the reviewed locations. In some parts of Australia, the NET-VISA associator built more mining related explosions than the automatic bulletin used for the reviewed bulletin.

Promotional text: Evaluation of NET_VISA with non-IMS stations.

P4.1-324 – IDC SHI Re-Engineering Alpha Tester Group

Authors: Thibault Arnal[1]; Helmuth Breitenfellner[1]; Balazs Zachar[1]; Marjan Bugarinovic[2]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Zuehlke Engineering, Austria*
Corresponding Author: thibault.arnal@ctbto.org

The PTS is leading the IDC SHI Reengineering project since 2014 with the goal of creating modernized, open-source software for SHI processing, and improving maintainability and extensibility to the system. Starting 2019, the project entered the Implementation phase and is currently under active development. The future system is based on the Geophysical Monitoring System (GMS) being developed for the US NDC. The aim of the Alpha Tester Group (ATG) is to enhance the engagement of the NDC community towards the IDC Reengineering project. It allows low-barrier access for State Signatories and NDCs to the current state of the reengineered system. The role of the ATG is to validate the results of the system, provide feedbacks on the system design and usability. This presentation highlights the challenges and technical solutions to provide and monitor test instances to our users around the world using cloud technologies.

Promotional text: In the context of the Alpha Tester Group on IDC SHI Reengineering, the PTS is providing test instances of the SHI data processing system being developed to participating NDCs. This presentation highlights the main challenges and chosen technical solutions.

P4.1-330 – Comparing the Performance of a Bayesian Automatic Waveform Event Associator (NET-VISA) with the Current Operational Approach (Global Association) at CTBTO. Minimum Detectability Maps for Simulated Explosions

Authors: Noriyuki Kushida[1]; Ronan Le Bras[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: noriyuki.kushida@ctbto.org

The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) has been developing and testing NET-VISA, Bayesian automatic waveform event detector, whilst a conventional detector, Global Association (GA), is in operation. In the context of CTBT verification regime, knowing the location dependency of the minimum detectable magnitude of those two event detectors is of interest. In the presentation, the geographical distribution of the minimum detectable magnitude of those detectors will be examined using a synthetic event generator simulating expected arrivals from hypothetical explosions embedded in an actual data day. Two different data days are used for the simulations. One is chosen as representative of normal seismicity while the other is representative of particularly high seismic activity.

Promotional text: The presentation shows the performance of the currently operational waveform event detector and newly developed machine-learning event detector over synthetic seismic events.

P4.1-336 – Quality Control of Heterogeneous IMS Stations

Author: Kenneth Macpherson[1]
Co-authors: Staff of the Wilson Alaska Technical Center[1]
[1]*University of Alaska, Fairbanks, AK, USA*
Corresponding Author: kamacpherson@alaska.edu

The Wilson Alaska Technical Center (WATC) at the University of Alaska Fairbanks operates a worldwide set of primary seismic, auxiliary seismic, and infrasound stations for the US Nuclear Arms Control Technology (NACT) Program and CTBTO. While WATC has long employed tools focused on data integrity, this project has expanded the quality control scheme to include data quality metrics that quantify noise performance, detect transient noise events, and identify metadata issues. The heterogeneous nature of WATC waveforms, which include broadband, short-period, and infrasound, presents challenges for established tools such as IRIS MUSTANG/ISPAQ. We have developed scripts that extend the capabilities of existing tools beyond conventional seismic channels, allowing us to generate comprehensive network intelligence that informs upstream quality assurance efforts. This presentation describes the system, demonstrates examples of data defects that have been identified, and outlines general spatio-temporal network performance indicated by almost a year of metrics. Finally, we demonstrate the results of applying aspects of the system to evaluate the data quality effects of deploying a small wind turbine in the vicinity of a colocated broadband and infrasound station. This work was supported by the NACT Program at Defense Threat Reduction Agency. Approved for public release; Distribution is unlimited.
Promotional text: High quality data is crucial for nuclear test monitoring and verification. This presentation will outline a system that is employed for identifying data defects and generating metrics that can then be used to improve network performance, contributing to enhanced test monitoring.

P4.1-339 – Controlled Underwater Explosions of World War II Ordnance

Authors: Paulina Bittner[1]; Ronan Le Bras[1]; Pierrick Mialle[1]; Peter Louring Nielsen[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: paulina.bittner@ctbto.org

World War 2 (WW2) devastated Europe between 1939 and 1945. Unexploded ordnances remaining from this conflict are still found in European harbours. These recovered ordnances are moved to remote locations and destroyed in a controlled way. Some underwater detonations were large enough to be recorded by the International Monitoring System (IMS). Related events were included in the International Data Centre (IDC) bulletins. Position and charge size of WW2 ordnances are well documented in the press as they are of interest to the residents of affected areas. This information may be used to assess location accuracy and estimated magnitude of events recorded by the IMS network. This presentation will show recordings of events linked to controlled underwater explosions of WW2 ordnances in 2020. Examined events were triggered by devices of different charge size and took place in several locations. There were also other, previously detected WW2 ordnance underwater explosions which could be compared to events in 2020. We present how accurately these relatively small explosions are located by the IMS network. We also relate charge size of explosive material to event magnitude in this special case of well-coupled underwater explosion.
Promotional text: Events triggered by controlled explosions of ordnances remaining from armed conflicts may be used to assess the location accuracy and magnitude estimates provided by the IMS network.

P4.1-365 – Participation of the Austrian NDC in NPE 2019

Author: Ulrike Mitterbauer[1]
Co-authors: Christian Maurer[1]; Maria-Theresia Apoloner[1]; Johannes Sterba[2]
[1]*Central Institute for Meteorology and Geodynamics (ZAMG), Vienna, Austria*
[2]*Technische Universität (TU), Vienna, Austria*
Corresponding Author: ulrike.mitterbauer@zamg.ac.at

Following the statement of the state of Raetia regarding an accident at a TRIGA reactor facility, the Austrian NDC started investigating a possible violation of the Test-Ban Treaty. Based on a list of IMS radionuclide detections a forward run was performed and Possible Source Regions were determined. However, the detections could not be traced back unambiguously to the location of the reactor. Especially, the forward simulation supported the hypothesis that radioxenon measurements from IMS station Schauinsland were not related to the TRIGA reactor. In agreement with atmospheric transport modeling (ATM) results radionuclide analysis revealed the possibility of two overlapping incidents. Possibly, a second event took place around three days before the announced reactor release. Additional data was released over a three months period. The second release contained radionuclide records from the national station in Vienna. ATM in combination with radionuclide analysis supported the hypothesis of a second event. The last data released, was seismic data from local non-IMS-networks. With the data and public available bulletins, analysis of the waveforms was started. Finally, a suspicious source, an explosion, was localized and identified. However, it was not possible to relate this event to the radionuclide measurements at Schauinsland and at Vienna via ATM.
Promotional text: Participation of the Austrian NDC in the NPE2019-Exercise.

P4.1-446 – Twenty Years of IDC Reviewed Event Bulletin (REB) Statistics Using Data from a Sparse IMS Network to One Reaching Near Completion

Author: Ronan Le Bras[1]
Co-authors: Gerhard Graham[1]; Fekadu Kebede Alamneh[1]; Sherif Mohamed Ali[1]; Paulina Bittner[1]; Paulino Feitio[1]; Jane Gore[1]; Ezekiel Jonathan[1]; Urtnasan Khukhuudei[1]; Ali Kasmi[1]; Tea Mumladze[1]; Ehsan Qorbani[1]; Marcela Villarroel[1]; Beatriz Vera[1]; Haijun Wang[1]; Margaret Wiggins-Grandison[1]; Hussam Alrshdan[1]; David Applbaum[1]; Parfait Noel Eloumala Onana[1]; Aaron Joseph Gutierrez Jimenez[1]; Ivana Jukic[1]; Leonid Kolesnykov[1]; Mariia Makhonina[1]; Kwangwari Marimira[1]; Tatiana Medinskaya[1]; Onkgopotse Ntibinyane[1]; Baby Jane Punongbayan[1]; Miguel Palma Perez[1]; Sleyde Paola Quintero Colorado[1]; Pa Pa Tun[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: ronan.lebras@ctbto.org

As of 14 December 2020, almost 90% of the IMS facilities (including radionuclide laboratories) were installed and certified, data is transmitted in either real time or on request from IMS stations to IDC for processing and analyzing. IDC analysts review automatic bulletins generated continuously and release the Reviewed Event Bulletin (REB) on a daily basis since February 2000. We present the statistics of mostly natural seismicity waveform events processed and analyzed over the past 20 years, as the network grew in size and became established. In particular, multiple parameters including magnitude for those events associated with detections from seismic, hydroacoustic and infrasonic stations are analyzed. Techniques and rules related to waveform data analysis and the need to correct the automatic bulletin are discussed. This discussion should be beneficial for analysts work and data processing system optimization.
Promotional text: We present the statistics of mostly natural seismicity waveform events processed and analyzed over the past 20 years, multiple parameters including magnitude for those events associated with detections from seismic, hydroacoustic and infrasonic stations are analyzed.

P4.1-455 – Tuning the IMS Seismic Stations by Optimizing Their Detection Thresholds

Authors: Christos Saragiotis[1]; Ivan Kitov[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: christos.saragiotis@ctbto.org

Two principal performance measures of the International Monitoring System (IMS) stations detection capability are the rate of automatic detections associated with events in the Reviewed Event Bulletin (REB) or precision of the REB and the rate of detections manually added to the REB or miss rate of the REB. These two metrics are significantly influenced by prespecified slowness-, frequency and azimuth- dependent detection thresholds used in the short-term average over long-term average ratio detection scheme of the IMS stations. The thresholds should be set at optimal values that a) the miss rate is as low as possible since no nuclear explosion should go unnoticed by the IMS and b) the precision is as high as possible as low precision compromises the quality of the automatically generated event lists and adds heavy and unnecessary workload to the seismic analysts during the interactive processing stage. In this abstract we present the procedure for optimizing the STA/LTA detection thresholds and how these new values are expected to impact the associated phases and added phases rates and other performance measures.
Promotional text: Optimization of STA/LTA detection thresholds at the IMS seismic stations and its expected impact on the association (or hit) rate and added phases (or miss) rate.

P4.1-593 – Methods to Assess the Value of High Input Resolution in Atmospheric Transport Models

Authors: Donald Morton[1]; Delia Arnold[2]; Jolanta Kusmierczyk-Michulec[3]; Pierre Bourgouin[4]
[1]*Boreal Scientific Computing, Fairbanks, Alaska, USA*
[2]*Arnold Scientific Consulting, Spain*
[3]*CTBTO Preparatory Commission, Vienna, Austria*
[4]*Former CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: don.morton@borealscicomp.com

The question of whether the increased cost of implementing higher input resolutions in atmospheric transport models is difficult to address, and any answer is typically qualified with an "it depends." Attempts to study the effects of high resolution are frequently performed with a small set of case studies, making it difficult to generalise the findings to other cases that may vary in a number of attributes. Our group has developed a methodology to run hundreds to thousands of paired ATM (FLEXPART) simulations in which only the resolution is varied, evaluating metrics such as plume arrival time and concentration, and then looking for "signatures" over many simulations that may reveal significant differences due to resolution alone. We suggest that if there are general improvements due to higher resolution, they must exhibit such signatures, and once they are detected they are further scrutinised. The methods have been used to explore paired FLEXPART simulations driven by 0.5 vs 1.0 degree ECMWF and GFS meteorological inputs every 36 hours over periods of eight to twelve months.
Promotional text: This work describes a framework that facilitates rigorous comparison of model parameters to determine whether differences affect simulations in significant ways.

P4.1-595 – Investigation of Improvement Possibilities for Source Localization Using High-Resolution Atmospheric Transport Modelling Within the Framework of the CTBT: Application to ^{133}Xe Observations at IMS Station RN33 in Germany

Author: Anne Tipka[1]
Co-authors: Jolanta Kusmierczyk-Michulec[1]; Martin B. Kalinowski[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: anne.tipka@ctbto.org

The IDC investigates the utilization of High-Resolution Atmospheric Transport Modelling (HRATM) in the CTBTO's aim to locate possible source regions after detections of radioactive substances through the International Monitoring System (IMS). Supporting the decision process, the IDC accomplished a case study with two approaches; using the current operational atmospheric transport model FLEXPART on a regional domain with 0.1 degree horizontal and 1 hourly temporal resolution, and the Weather Research and Forecasting Model (WRF) which serves as an interface between the driving meteorological data and the HRATM FLEXPART-WRF to further increase the resolution. Optimizations of settings were done by a WRF sensitivity study. The performance was evaluated by using ATM backward simulations and their comparison with observational data which are comprised of seven episodes of elevated Xe-133 concentrations from the IMS noble gas system DEX33, located in Germany. Each episode consists of 6 to 11 subsequent samples with each sample being taken over 24 hours. Both FLEXPART models used the source terms from a medical isotope production facility in Belgium to simulate the resulting concentration time series at the DEX33 station. Statistical metrics are used for comparison.
Promotional text: This presentation describes the results from a case study which was conducted to support the decision process on applying HRATM at the CTBT. Simulation results from two HRATM approaches were compared to measurements from the IMS station DEX33.

P4.1-613 – Seismological Investigation of the NPE2019

Author: Nicolai Johannes Gestermann[1]
Co-author: J. Ole Ross[1]
[1]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
Corresponding Author: nicolai.gestermann@bgr.de

The NDC Preparedness Exercises (NPE) are regularly performed dealing with fictitious treaty violations to practice the combined analysis of CTBT verification technologies. These exercises should help to evaluate the effectiveness of analysis procedures applied at NDCs and the quality, completeness and usefulness of IDC products. The NPE2019 is a combined radionuclide-waveform scenario. The source region and time domain of a possible treaty violation activity was determined from ATM in backtracking mode with input data from fictitious particulate radionuclide and radioxenon measurements at stations of the IMS of the CTBTO. The seismicity of the determined source region was investigated in detail to identify events which cannot be classified as natural. An earthquake sequence could be identified within the specified source region and time frame from ATM analysis. The unusual shallow source depth of about 3 km and no mining activities in this region could classified these events as a possible treaty violation. Results were used to decide about the need of an OSI to answer this question.
Promotional text: Investigation of seismic events within the NDC Preparedness Exercises 2019 (NPE-2019) target area to identify the nature of these events and decide about a potential treaty violation.

T4.3 Information Technology, Power Systems and Other Enabling Technologies

Highlights

Data Handling and Communication

O4.3-167 showed how use of the NDC in a box software suite on cloud platforms could expand NDC capabilities and their use of IMS data by using cloud resources to perform analysis and data pulls, thereby reducing local bandwidth and infrastructure issues. Investigated solutions included the use of VirtualBox virtual machines, Docker containers and Amazon Machine Images (AMIs) on Elastic Compute Cloud virtual hardware in the Amazon Web Services commercial cloud. Thus far, AMIs seem to offer the best balance of high configurability and low resource usage.

Cloud migrations were the topic of presentation P4.3-470 by General Dynamics Mission Systems (GDMS) (USA). GDMS cloud migration consists of moving new and existing applications to a cloud-ready architecture, creating new cloud infrastructure and services and incorporating cloud solutions in backup plans. Docker container applications enable greater flexibility for platforms, are scalable and offer easier maintenance than virtual machines. Kubernetes was chosen as the orchestration tool.

P4.3-267 described an engineering effort to mitigate the impact of data loss scenarios of IMS hydroacoustic hydrophone stations by improving onshore digital data handling equipment. A local disk buffer storing hydrophone and diagnostic data was added. This buffer is accessible through newly developed standard station interface (SSI) functionalities, which allow backfilling of user-specified data segments and retrieval of diagnostic data logs by remote user request. The enhanced backfilling makes it possible to recover from data loss. Roll-out of these new capabilities at hydroacoustic stations HA1 (Australia), HA3 (Chile) and HA4 (France) is planned for 2021–2022.

P4.3-334 described a new configurator developed for SSI, a modular software that collects, signs, buffers, reformats and transmits data using the IDC format. SSI is used at more than 150 IMS stations in all waveform technologies as well as at several NDCs. The new configurator is developed in Python and runs on both Linux and Windows. The back end compresses the entire configuration into one file before sending it to the front end. When a change is done, the front end zips the configuration into one file before sending it to the back end. The new configurator has a more user friendly interface and will make it easier to configure SSI over a low bandwidth link.

P4.3-570 gave an overview of how information from a network management system can be used to analyse outages in data transmission to determine the root cause and identify necessary infrastructure improvements. A specific problem of the Global Communications Infrastructure (GCI) links was analysed, where occasionally even without a failure in data acquisition (it eventually backfills), there may still be long lapses in data transmission.

P4.3-414 described the main design changes to the Experts Communication System (ECS). The ECS is a secure, Internet-accessible application that enables registered users from States Signatories and the PTS to access official CTBTO documents and other material. The present work added a new user interface and reorganized all available information in a more user friendly and robust way. In addition, the ECS source code will be refactored in a more robust way and legacy dependencies will be removed, with the principles of continuous integration/continuous delivery being introduced and deployment moved to a Docker environment.

P4.3-445 described a project to create a new email domain for verification data on a segregated infrastructure. Starting in 2017, the PTS built a new structure for its email systems that allows full segregation of the verification and non-verification email flows. The domain @ctbto.int was chosen for the verification systems. The presentation described the high level architecture design and the solutions developed for the new email domain.

P4.3-066 reported on good practices in SeisComP3 database management at the Central American Tsunami Advisory Center (CATAC) in Nicaragua. Data on every event is sent from the main database to three other real time servers, which are the front end for disseminating products. This mechanism aims to guarantee issuance of earthquake products in real time, with the data protected and available in the main database, servers and backups, avoiding unnecessary traffic that overloads the network. To achieve better compatibility with neighbouring countries, SeisComP was also adopted by the OVSICORI volcanic and seismological observatory in Costa Rica, as described in P4.3-140.

P4.3-418 reported on the development of an alert monitoring system for radionuclide monitoring station RN42 (Malaysia).

Power Systems and Hardware

Under a mandate to sustain high data availability throughout the IMS network, the Engineering and Development Section of the IMS Division launched an initiative, described in O4.3-266, to design next-generation power systems to strengthen the resiliency of IMS stations to catastrophic failures. Five standardized IMS power system prototypes were developed, certified and subjected to thorough factory acceptance testing. The prototypes are based on the open system architecture concept, utilizing ad hoc selection and substitution of various power sources and power system components derived from the environmental demands and logistical restrictions present at the station location. The new systems are undergoing long-period testing in field conditions at the FACT facility at Sandia National Laboratories (USA), with further tests scheduled at a test site in Alaska. O4.3-514 presented a modular power supply system developed by Enviroearth (France) and adapted to the IMS network. These power systems are all equipped with their own state of health information technology system that allows continuous monitoring. A series of plug and play equipment vaults and containerized system technologies have been optimized to fit all topologies and technologies of IMS stations.

P4.3-329 described a solution for the continuous power supply of seismic station AS43 (Indonesia). The lightning detector relay, coupled with a contactor type relay, is used to regulate the power supply, switching automatically between solar power and the main generator. This way, the charging of the battery is guaranteed, and data can be sent continuously. P4.3-571 discussed the problem of corrosion, which is especially acute for stations located near the sea, in high humidity and salty environments. Correct installation, proper maintenance and inspection are crucial for long term, sustainable operations. Proper installation, with emphasis on wires, termination, grommets and strain relief, is essential for avoiding later damage. New types of surge protection with indicators and replacement modules enable timely replacements, keeping the sites well protected from power surges.

P4.3-558 discussed challenges in using radio frequency links for intra-site communication at IMS waveform stations. Equipment obsolescence, aging, material deterioration or harsh environmental conditions may cause a drop in transmission. Roaming operation of the radios reduces the risk of having repeaters as the single point of failure. Regular preventive inspections and maintenance are essential in order to ensure stable radio links and to achieve the expected reliability over years of operation. P4.3-160 described the comprehensive guidelines and standards for grounding and lightning protection systems at IMS stations that were developed by the Engineering and Development Section of the IMS Division in cooperation with OVE Service (Austria). The first edition of the guidelines was issued in 2010 and then revised in 2018–2019. The standard has been implemented at more than 20 IMS stations, which has significantly reduced damage caused by lightning strikes and power surges.

P4.3-653 presented a model for the incorporation of a stronger energy power system for IMS stations, adapted to conditions in South America. Remote stations in the region face unique environmental conditions, including cloud forests, high vegetation and high precipitation levels, and would benefit from the incorporation of autonomous energy systems to ensure data availability.

P4.3-652 proposed the development and implementation of a tool for recording and sharing information about operational problems at IMS stations. The application, implemented internally in the station, would record the incidents and notify a group of contacts about the problem and its solution. It would also allow users to research previous similar events in order to apply similar solutions, thereby reducing maintenance time.

O4.3 Information Technology, Power Systems and Other Enabling Technologies Abstracts of Oral Presentations

O4.3-167 – Seismic-Hydroacoustic-Infrasound (SHI) in the Sky: Benefits and Pitfalls of NDC in a Box in the Cloud

Author: Gordon MacLeod[1]
Co-authors: Christopher Young[2]; Stephen Myers[3]; Jonathan MacCarthy[1]; Omar Marcillo[4]; Jonathan Burnett[5]
[1]*Los Alamos National Laboratory (LANL), Los Alamos, NM, USA*
[2]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
[3]*Lawrence Livermore National Laboratory (LLNL), Livermore, CA, USA*
[4]*Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, USA*
[5]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: macleod@lanl.gov

Capacity building efforts for National Data Centers (NDCs) commonly involve the provisioning and shipment of physical hardware systems and the training, installation, maintenance and distribution of the "National Data Centre (NDC)-in-a-Box" (NIAB) software suite. These fundamental functions (access to hardware and software) are the foundations of cloud computing. We investigate whether utilizing cloud infrastructure is feasible and beneficial to users of the IMS data and IDC software. We test using basic cloud computing and storage technologies to increase access and capacity for NDCs/users, to decrease cost and logistical burden, increase processing capabilities, and improve overall infrastructure reliability without losing the current level of local flexibility. We investigate the use of VirtualBox virtual machines (VMs), Docker containers, and Amazon Machine Images (AMIs) on elastic compute cloud (EC2) virtual hardware in the Amazon Web Services commercial cloud. Thus far we have found that AMIs offer the best balance of high configurability and low resource usage. Internal and external evaluations of AMIs containing NIAB Seismic, Hydroacoustic, and Infrasound (SHI) software and virtualized

desktop environments on EC2 instances note good desktop responsiveness and adequate computing and storage capacity.
Promotional text: The study shows how the use of the NIAB software on cloud platforms could expand NDC capabilities and their use of IMS data by performing the analysis and data pulls utilizing cloud resources, reducing local bandwidth and infrastructure issues.

O4.3-266 – Next-Generation IMS Power Systems: Current Status and the Way Forward

Author: Marian Jusko[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: marian.jusko@ctbto.org

With a strong mandate to sustain high annual data availability throughout the IMS network, IMS/ED launched the initiative to design the next-generation IMS power systems to strengthen IMS stations' resiliency to catastrophic failures, often arising from power-related issues. Five standardized IMS power system prototypes were developed, certified, and subjected to throughout factory-acceptance testing. The developed next-generation IMS power systems are based on the open system architecture concept, utilizing ad-hoc selection and substitution of various power sources and power system components derived from the environmental demands and logistical restrictions present at the station location. These purpose-built, yet standardized power systems thus adapt to the site-specific input and output requirements, without requiring extensive redesign and cost when deployed at other stations throughout the IMS network. The high degree of standardization simplifies installation, maintenance and future upgrades as components can be freely interchanged throughout their life cycle without impacting the overall system. The new IMS power systems are currently undergoing long-period testing in field conditions at the FACT facility at Sandia National Laboratories, with further tests scheduled at a test site in Alaska in 2021. The drafting and release of the IMS Power System Guidelines documentation is underway.
Promotional text: The main intent of this topic's submission is to share the experience and lessons learned from the development of the power systems, which are not only specific to the IMS, but have a wider reach of applicability and interest to perhaps other attendees of the SnT conference.

O4.3-514 – Presentation of Containerized Solution and Optimized Power Supply System

Author: Leopold Riom[1]
Co-author: Clement Bednarowicz[1]
[1]*Enviroearth, Saint-Cannat, France*
Corresponding Author: c.bednarowicz@enviroearth.fr

The aim of this presentation is to introduce a range of new engineering systems recently developed and installed by Enviroearth and adapted to the whole IMS network. We will present a modular power supply system which allows flexibility to answer to any power supply need and configuration over the global network. These power systems are all equipped with their own state of health IT system allowing a continuous monitoring of information on the system operation via an accessible and user friendly dashboard. We will also present a series of plug and play equipment vaults and containerized system technologies that have been optimized to fit with all the topologies and technologies of the station within the IMS network. Over the past few years, we have worked on the improvement and the standardization of these systems to target more robustness and sustainability leading to better station data availability. We would like to present this knowledge and expertise on these products and introduce state-of-the-art systems adapted to the needs of the CTBTO with a focus on the verification options and assets that they are all offering.
Promotional text: Containerized Solution Technology and Power Supply are the "how know" of Enviroearth. We have designed, optimized, tested, installed, and operated a wide range of these System Solutions over each IMS Station

technology and topology type and would like to present these knowledge.

P4.3 Information Technology, Power Systems and Other Enabling Technologies Abstracts of Poster Presentations

P4.3-066 – Methodology of Good Practices in Database Management at CATAC to Guarantee Issuance of Earthquakes Products in Real Time

Author: Miguel Angel Flores Ticay[1]
[1]*Instituto Nicaraguense de Estudios Territoriales (INETER), Managua, Nicaragua*
Corresponding Author: miguel.flores@ineter.gob.ni

Due to the large amount of information that is created with a new event and its relocation, the SeisComP3 (SC3) Database size tends to increase and the backup process becomes increasingly time-consuming. At CATAC (Central American Tsunami Advisory Center) we created a data import mechanism, to send the information referred of every event from the main database to three other real-time servers, which represent the front-end to disseminate products such as Hypocenter location, Focal Mechanism and Moment Tensor in the webpage and two SC-Processing Backups. We also implement this procedure to import solutions from the Earthquake Early Warning (EEW) Server to the main Server. Thanks to these good practices, we keep data protected and available into the main database, servers, and backups avoiding unnecessary traffic that overloads the network. In every server, queries are made directly at the localhost level so there's no network traffic and the main server is not saturated at all. Additionally, in case of IT chaos in our datacenter provoked by a natural disaster or another, there will be no data loss.
Promotional text: Methodology of Good Practices in SeisComP3 Databases Management at CATAC to Guarantee Issuance of Earthquakes Products in Real Time for Making-decision, Hazard Assessment and Risk Mitigation.

P4.3-140 – Transition to SeisComP on OVSICORI

Author: Christian Garita[1]
[1]*Observatorio Vulcanologico y Sismologico de Costa Rica (OVSICORI), Heredia, Costa Rica*
Corresponding Author: cgarita@una.cr

OVSICORI is the institute in charge of earthquake and volcanoes monitoring in Costa Rica. Similar to other countries in Central America, we have limited economical resources. Thanks to an important government investment in 2010 we chose Antelope by BRTT as our main monitoring computational system. Antelope worked well for us at the beginning, but over the following years we found out that most of the countries around us were using Seiscomp. In some ways, this prevented us from sharing data and knowledge with our neighbours. Seiscomp has developed faster than Antelope and we have therefore found some procedures easier on Seiscomp than on our system. In 2018 CTBTO invited us to the Basic Seiscomp Training which helped us understand the system. This course was the beginning of the transition for us. In 2020, COVID-19 affected the national economy and so we were unable to afford Antelope's license. At the end of 2020, the transition to Seiscomp began.
Promotional text: Transition to Seiscomp on OVSICORI. Our institute decide to explore SeisComP3 system after CTBTO course.

P4.3-160 – IMS Guidelines: Minimum Standard for Grounding and Lightning Protection System at the IMS Stations. Standard Content, Implementation and Its Influence on Data Availability Statistics

Authors: Pavel Martysevich[1]; Gerhard Diendorfer[2]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*OVE Service GmbH, Vienna, Austria*
Corresponding Author: pavel.martysevich@ctbto.org

Based on statistics and experience in station installation and operations, IMS/ED in cooperation with OVE developed a comprehensive guidelines/company standards for a grounding and lightning protection system at IMS stations. The document's first edition was issued in 2010 and then revised in 2018-2019. The document provides comprehensive information for the design and implementation of the grounding and lightning protection system for all four IMS technologies. The guidelines steadily became an integrated part of all terms of references for IMS stations' installations and upgrades. The standard has been implemented at over 20 IMS stations, which lead to significant reduction of damages caused by lightning strikes and power surges in the IMS network and, consequently, to increased data availability in the IMS network. The poster presents the main parts of the standard, statistics of standard implementation and associated data availability changes at affected stations.

P4.3-267 – Safeguarding Data Availability at IMS Hydroacoustic Hydrophone Stations by Improving On-Shore Digital Data Handling Equipment

Authors: Mario Zampolli[1]; Jerry Stanley[1]; Georgios Haralabus[1]; Moctar Moumouni Kountche[1]; Manuel Hojesky[2]; Jeff Jenneve[3]; Peter Jorgensen[3]; Doug Bowlus[4]; Guy Cekada[3]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Zuehlke Engineering, Austria*
[3]*L3Harris MariPro, Inc., Goleta, CA, USA*
[4]*Subsea Circuits, Inc., California, USA*
Corresponding Author: mario.zampolli@ctbto.org

The IMS hydroacoustic (HA) network monitors continuously the world's oceans with only six hydrophone stations (11 triplets). The acoustic signals acquired by the hydrophones are digitized underwater and transmitted via fibre-optic cable to an on-shore Digital Data Formatting Interface (DDFI). The DDFI builds data packets and sends these to the Commission's Standard Station Interface (SSI), where CD1.1 data frames are formed and forwarded to Vienna via satellite. Loss of data from even a single triplet has a high impact on the network's overall coverage and is often associated with the following root causes: SSI malfunction, local DDFI-SSI network or satellite transmission issues. An engineering effort was undertaken to mitigate the impact of such data-loss scenarios by adding to the DDFI a local disk buffer storing hydrophone and diagnostic data. This buffer is accessible through newly developed SSI functionalities, which allow backfilling of user-specified data segments and retrieval of diagnostic data logs by remote user request. The enhanced backfilling makes it possible to recover from the above described data-loss situations, whereas remote retrieval of DDFI diagnostic data leads to more efficient station troubleshooting. Rollout of these new capabilities to HA01, HA03 and HA04 is being planned for the period 2021-2022.

Promotional text: Newly developed shore equipment features make it possible to reduce data loss and improve the remote troubleshooting of IMS Hydroacoustic hydrophone stations. Roll-out to HA01, HA03 and HA04 is being planned.

P4.3-329 – A Solution for the Continuous Power Supply of the AS43 Station

Author: Hendro Subekti[1]
[1]*Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), Jakarta, Indonesia*
Corresponding Author: bekti024@yahoo.co.id

The CTBTO site station in Parapat (AS043), North Sumatra has been losing data since 2020. This has resulted in the loss of important data for analysis. Data analysis from SQLX shows the seismometer in good condition and noise spectrum still within HNM / LNM limits. The site station has used solar panels but this is not enough. Solar panel energy cannot supply battery power effectively. The solar panels work for about 4 hours. Due to the Parapat climate it is almost cloudy every day. The LDR (lightning detector relay) is designed to regulate the supply of power sources from the consumption of solar power and the main generator. This way, the battery can always be fully charged. Therefore, data can be sent continuously. The LDR is intended for automatic switching between the generator and solar panels coupled with a contactor type relay. This is not a new technology, just a simple solution to ensure continuous data availability without interruption. Noise studies have not been carried out, but the converter can be located outside the seismograph area. The generator power supply is used because only that device may be available in the vicinity of the site.
Promotional text: Transfer power supply from solar panel to main generator for AS043.

P4.3-334 – The SSI New Configurator

Authors: Moctar Moumouni Kountche[1]; Julien Marty[1]; Benoit Doury[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: moctar.moumouni.kountche@ctbto.org

The Station Standard Interface (SSI) is a modular software, consisting of a set of executable programs, application programming interfaces (API) and libraries. The main purpose of SSI is to collect, sign, buffer, reformat and transmit data using IDC format. SSI is used at more than 150 IMS stations in all waveform technologies as well as at several NDCs. The Web configurator has been the main interface for operators to configure SSI, however this web interface can appear as complex and sometimes not so user-friendly. One of the major issues of this configurator is that it's challenging to configure SSI over a low bandwidth link. A new configurator was then developed to fill the gaps and difficulties of the previous interface and compatible with CTBTO network infrastructure. This new configurator is a fat client developed in Python running on both Linux and Windows. The backend compresses the entire configuration in one file before sending it to the frontend. The file is then read by the frontend which will display information in a user-friendly way for reading or modification. When a change is done in the configuration, the frontend will zip the configuration in one file before sending it to the backend.
Promotional text: The management of continuous and efficient station data acquisition and data forwarding to the IDC is a key functionality of IMS stations with deficiencies impacting directly the station performance.

P4.3-414 – The Experts Communication System

Author: Roberta Nettuno[1]
Co-author: Lucas Ferreira[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: lucas.ferreira@ctbto.org

The Expert Communications System (ECS) is a secure internet-accessible application, sharing and strengthening the intersessional work of the Commission and its subsidiary bodies, that enables registered users from States Signatories, the Provisional Technical Secretariat (PTS) and a restricted observers' number to the Preparatory Commission (PC) to access to official documents. Users can launch or participate in discussions related to the ongoing and forthcoming meetings of the Commission and its subsidiary bodies or access documents' drafts. Live streaming and on-demand videos of meetings and as well as related information are also available on ECS. Recently work has begun to redesign ECS by adding a new user interface and to adhere to the corporate identity standards, referenced in the CTBTO Style Manual, and to re-organize all available information in a more user-friendly way to support needs, comments and feedback collected from registered members and observers. Moreover, ECS is undergoing a process to refactor its source code in a more robust way, removing old legacy dependencies, and introducing the principles of CD/CI as well as moving deployment to a Docker environment. The proposed e-poster will showcase the main design changes in ECS, and the software architecture enhancements and solutions applied to the system.

Promotional text: The ECS is an important tool for sharing and strengthening the intersessional work of the Commission and its subsidiary bodies.

P4.3-418 – Development of Alert Monitoring System for the Malaysian Radionuclide Monitoring Station (RN42)

Authors: Mohd Fauzi Bin Haris[1]; Muhammed Zulfakar Zolkaffly[1]
Co-authors: Saaidi Ismail[1]; Mohd Dzul Aiman Aslan[1]; Muhammad Rawi Md. Zin[1]; Mohd Faisal Izwan Abd Rashid[1]; Norita Md. Norwawi[1]
[1]*Malaysia Nuclear Agency, Selangor, Malaysia*
Corresponding Author: fauziharis@gmail.com

Among the monitoring stations include the RN42 which is located in Cameron Highlands, Pahang, Malaysia. Generally, the task to monitor the status and result of the radioactivity spectrum is quite a tedious job. The radionuclide analyst at the International Data Centre (IDC) in Vienna, Austria analyzed around 21 to 25 spectrum data every day. Automatic products help the analyst to perform subsequent interactive analysis. However, from the National Data Centre (NDC) point of view, the task of monitoring the result is only part of their other routine task. Consequently, they could miss important events that happened at their stations that require immediate response. This paper aims at discussing the development of a simple alert system for monitoring the health of the RN42 station. The preliminary data (PREL) which is collected and received every two hours are chosen in this study as the parameter of interest, including the existence of natural radionuclides such as Beryllium-7 (Be-7) and Sodium-24 (Na-24) as indicator. The alert system has been developed using Python and integrated with existing client email software. Alert will be sent to the authorized recipient to their smartphone using Telegram Bot and could be displayed in a simple webpage.

Promotional text: A simple but effective method to alert NDC staff and stakeholders about what is happening on their stations as well as important alerts about any important detection which answering the first objective of this conference.

P4.3-445 – Segregation of the Verification Email Flow in the CTBTO

Authors: Lucas Ferreira[1]; Alexander Sudakov[1]; Michaela Lang[1]; Menachem Amir[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: lucas.ferreira@ctbto.org

The PTS uses email (SMTP) as a transport mechanism for a portion of the verification data received from the IMS stations and laboratories and for data transmitted to States Signatories. Currently the PTS uses the email domain @ctbto.org for both its verification and non-verification email systems, forcing the sharing of resources and making it difficult to segregate the email flows and systems. Starting in 2017, the PTS built a new structure for its email systems that allows for the full segregation of the verification and non-verification email flows. The domain @ctbto.int was chosen for the verification systems. The basic infrastructure was assembled and made available to PTS teams. Software solutions are being developed to allow the use of the new email domain. This presentation will describe the high-level architecture design and the solutions developed for the new email domain. It will also highlight the challenges to implement the new design, such as the need to change the configuration of the IMS stations.

Promotional text: The PTS uses email as a transport mechanism for verification and non-verification systems and identified the need to segregate verification email flows. This presentation describes the project to create a new email domain for verification data on a segregated infrastructure.

P4.3-470 – GDMS US–IMS Cloud Migrations

Author: Dennis Bustillo[1]
[1]*General Dynamics Mission Systems (GDMS), Chantilly, VA, USA*
Corresponding Author: dennis.bustillo@gd-ms.com

General Dynamics Mission Systems (GDMS) is seeking ways to improve the maintainability and scalability of its applications and IT infrastructure by leveraging emerging cloud technology and best practices. The cloud offers many advantages over traditional IT infrastructures including greater flexibility, reduced cost, improved backup solutions and faster deployment cycles. GDMS cloud migration consist of moving new and existing application to a cloud-ready architecture, creating new cloud infrastructure and services and incorporating cloud solutions in backup plans. Cloud applications are developed as a collection of smaller services which are deployed as containerized services. Legacy monolith applications are refactored into a design that allows for containerization of individual services. Applications are then deployed and managed using container orchestration services. Kubernetes was chosen as the orchestration tool because of its maturity and flexibility. Finally, data and artifacts are stored in cloud databases and other cloud backup solutions for persistent, off-site and unlimited data storage capability.

Promotional text: GDMS migrates IT infrastructure to Cloud solutions to improve maintainability and scalability of applications and services. The migration consist of developing applications for the clouds, managing deployed applications using Kubernetes and leveraging cloud backup solutions.

P4.3-558 – Challenges in Using RF Link for Intra-Site Communication at IMS Waveform Stations

Authors: Stefka Stefanova[1]; Claus Johannsen[1]; Sergelen Bazarragchaa[2]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Former CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: stefka.stefanova@ctbto.org

Radio frequency (RF) systems are used at large number of IMS waveform stations for transmitting data and State-of-Health parameters from the array elements to the Central Recording facility. Main operation and maintenance challenges experienced over time are related to equipment obsolescence, aging, material deterioration or harsh environmental

conditions. RF equipment must receive regular preventive inspections and maintenance in order to ensure stable radio links and to achieve expected reliability over years of operation. Unnecessary downtime can be avoided by implementing efficient technical solutions and by having regular maintenance of RF transmission equipment, by performing appropriate monitoring of critical parameters and by having recourse of qualified RF engineers for design, implementation and training of station operators. This paper describes the challenges faced with RF systems used at IMS waveform stations and focusses on the successes with operation and maintenance and on the solutions to mitigate the radio communication problems.
Promotional text: This paper describes the challenges faced with RF systems used at IMS waveform stations and focusses on the successes with operation and maintenance and on the solutions to mitigate the radio communication problems.

P4.3-570 – GCI, Station and NDC Infrastructure Resilience Optimization

Authors: Shaun Kennedy[1]; Michael Guenther[1]; Walid Mohammad[1]; Mario Zampolli[1]; Julien Marty[1]; Jose Pereira[1]; Pavel Martysevich[1]; Alfred Kramer[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: shaun.kennedy@ctbto.org

Since the migration to GCI – III it has been observed that there are multiple instances of failure of data transmission when there is an operational GCI-link. Elements for significant consideration in the analysis phase examined why, when the GCI link is available, data transmission stops but subsequently backfills indicating that there is some element in the overall data path that is temporarily failing. Ensure that the GCI equipment is connected to the appropriate power source at the stations. As the backup GCI-link has a lower overall consumption than the primary it may be appropriate to connect it to the data acquisition same power source if it, in conjunction with the reliability of the recharging capability is considered to have sufficient capacity that data acquisition is not put at risk. Due to complexities in the data acquisition path, particularly when the station is run by, in effect a separate entity there is a firewall or other network elements between the actual acquisition equipment and the PTS SSI machine, understanding the actual full data flows and improving automated monitoring and alerting could improve data availability.
Promotional text: Use on Network Monitoring Data to analyse and rectify configuration issue, improve availability and predict potential issues to be rectified by preventative action leading to increased data availability.

P4.3-571 – Challenges and Improvements to DC Power Systems at IMS Waveform Stations

Author: Claus Johannsen[1]
Co-authors: Stefka Stefanova[1]; Palmer Yao[2]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Former CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: claus.johannsen@ctbto.org

Most waveform stations in the IMS network are now 10-20 years old. Problems with power and communication systems often relate to cables, circuit breakers, connectors and/or surge protection becoming corroded or deteriorated to a point where good connections and functionality can be compromised. Many stations are located near the sea, in high humidity and salty environments, which inevitably provokes corrosion over time, almost regardless of precautions during installation to protect the electrical installations. In addition, DC power installations are prone to create a constant ion flow that can create electrolysis and could damage metals in the installation. Examples of corrosion has been observed on cables, connectors and surge protection devices and shows the importance of proper installation, timely inspection and periodic maintenance of the power and communication systems, to ensure sustainable operation and high data availability of IMS stations. Installation methods to simplify

inspection and maintenance can help the station operators during troubleshooting and to report power issues before they become problems. This paper describes some of the power systems installed at IMS waveform stations and focusses on the operation and maintenance of these power systems.
Promotional text: DC power systems maintenance and repair, degradation due to time, humidity, etc. State of the art components for DC power and surge protection.

P4.3-652 – Implementation of a Tool for Recording and Consulting the Most Frequent Problems in a Station

Authors: Fernando Villacis[1]; Sergio Suarez[1]; Cesar Robalino Ponce[1]
[1]*Instituto Oceanográfico y Antártico de la Armada del Ecuador, Ecuador*
Corresponding Authors: sergio.suarez@inocar.mil.ec, fernando.villacis@inocar.mil.ec, cesar.robalino@inocar.mil.ec

This study proposes the development and implementation of a tool for recording and consulting the problems that occur at the station. The application to be implemented internally in the station, which can be mobile, would record the incident and once the event has been added, a group of contacts would be notified about the problem that occurred and its solution. In turn, the application would allow the query of previous similar events in order to apply a similar solution, reducing maintenance time. This knowledge base must be able to store multimedia files, such as images and videos, in order to facilitate maintenance. These multimedia files will be used to implement augmented reality technology, further facilitating the access and location of the station components. The application will have an external navigation mode that allows the location of the infrasound sensors and the distance between all its components and an internal navigation mode, virtual tour type, dynamically optimizing the location of parts or modules of any type of station, which seeks to perform a more efficient maintenance of station components.
Promotional text: The station staff changes each 1 or 2 years, which causes difficulty in the transmission of knowledge and loss of traceability about the problems that the equipment has had and how to solve them.

P4.3-653 – Power Energy Model to Improve Data Availability of IMS, Adapted to South America Seismic Stations Site Conditions

Author: Ana Maria Perez Zeledon[1]
Co-author: Ricardo Jose Lopez Rubio[1]
[1]*Fundación Venezolana de Investigaciones Sismológicas (FUNVISIS), Caracas, Venezuela*
Corresponding Author: anazeledonfunvisis@gmail.com

Remote places, away from crowded areas, where anthropic noise cannot affect the quality of the measurement characterize the site of installation of a seismological station. However, these sites are generally difficult to access, located in places where there are no traditional energy and communication systems, or the access to maintenance facilities affects its operability. This condition could for long periods affect the availability of the data generated by seismological stations connected to traditional energy systems, due to failures in the traditional electricity service. From this approach, the incorporation of autonomous energy systems is an alternative solution. However, in South America given the diversity of climates, with the presence of cloud forests, high vegetation and average precipitation levels between 350 and 2500 mm per year, the incorporation of autonomous energy systems to ensure the data availability of the seismic stations of the IMS - and therefore mission capable - represent a challenge. The purpose of this research is present a model for the incorporation of a stronger energy power system for IMS stations, adapting to South American region conditions. The results shared a contribution to improve IMS seismic station data availability, using an alternative system energy and considerations for its implementation.
Promotional text: Through the research, we can identify a

potential and adaptive solution to improve the performance of the IMS seismic stations contributing to verification regime. Present this proposed in the SnT scenery is an opportunity to adjust and improve the research through the exchange.

T4.4 Network Sustainability and Systems Engineering for CTBT Verification

Highlights

O4.4-528 reported on several methods the IMS Maintenance Unit has implemented to improve data availability. These include equipment standardization, infrastructure improvements, improved equipment sparing, improved hands-on technical training, better documentation, and implementation of secure shipping of HPGe detectors. Equipment standardization has made sparing, training and documentation efficient and effective. It was shown that state of health monitoring of HPGe detector crystal temperatures allowed preventative maintenance to be applied prior to failures, and on-site detector vacuum restoration allowed rapid recovery of the stations. Despite COVID-19, data availability averaged over all technologies was highest in 2020. Future challenges include an aging IMS network, continued completion and expansion of the network of certified stations under a constant maintenance budget, and no increase in staffing.

Sustainment of the IMS hydrophone hydroacoustic network is very challenging. P4.4-276 summarized the ongoing sustainment projects of the IMS through solutions for the re-establishment of damaged sections, risk mitigation studies and protective measures. Innovative modular solutions for easy repair of underwater components and enhanced resilience were described, together with protective measures for the onshore electronics.

P4.4-152 focused on the station state of health monitoring capability developed within the Geophysical Monitoring System (GMS) project. This capability was provided to the IDC in the 2020 GMS open source release. The monitoring application is designed to receive, process and display state of health information from at least 300 stations using the CD-1.1 protocol. O4.4-209 reported on results using predictive monitoring software when applied to the RASA aerosol sampling system. The benefits of predictive monitoring were demonstrated by showing how a sampling pump failure of the SAUNA noble gas system at IMS station RN77 (USA) was detected early. Ongoing work aims to develop models to understand IMS station state of health data and trends as well as algorithms to integrate predictive monitoring into the state of health data analysis.

P4.4-382 described a field deployable system to validate the performance of the mass flow meters of RASA systems. The Rig for Automated Flow Testing (RAFT) system can validate the factory calibrations of the flow meters, characterize the impact of RASA ductwork on flow rate measurements at various operating ranges and perform flow validation measurements in line with CTBT certification/revalidation procedures for particulate systems.

P4.4-139 reported on how data science can facilitate predictive maintenance of noble gas systems within the IMS. Data driven and model driven approaches to analyse state of health data were used, with the goal to detect component failures and develop preventive maintenance techniques. A hybrid methodology that combines both data driven and physics based approaches can more accurately predict system failures and extend the prediction window.

O4.4-135 and P4.4-134 reported on the operation of a temporary IMS seismic station during the major upgrade of the 25 element PS19 seismic array (Germany). The upgrade in 2017–2018 involved intra-array cabling, power, infrastructure and data acquisition work, which rendered the main array unusable and resulted in a general shutdown of the array for 18 months. As a result, a temporary 10 element array was constructed to maintain data availability for this primary IMS seismic station. During its operation, the temporary array detected signals from the 2017 event in the Democratic People's Republic of Korea. With minimal impact on seismic monitoring during the upgrade, and a cost of about US$200,000, the temporary array proved to be a valuable investment.

P4.4-049 reported on upgrades to seismic station PS45 (Ukraine). These included installing fibre-optic communication lines, upgrading the power supply system and replacing the lightning protection and equipment. The upgrades resulted in an increase in data availability, from 86 per cent in 2015 to 99.9 per cent in 2020.

P4.4-189 described the operation of two portable infrasound stations that were installed in 2019 in Bermuda, in parallel with the existing IS51 elements. This solution was pursued as a result of operational difficulties at the existing site. Data was collected for 10 months to assess whether the additional elements benefited the capability of the station to detect infrasound events.

P4.4-664 provided an overview of the installation and operation of the six NORSAR (Norway) IMS stations, with emphasis on the set-up of a new state of health monitoring system and lessons learned so far. P4.4-686 described the successful operation and maintenance of the autonomously recording broadband stations of the Botswana Seismological Network, including lessons learned during the COVID-19 pandemic.

P4.4-257 presented the different development phases of the OSI Technology Testing Programme. The programme is designed to formalize the technology testing process, from the definition of user requirements to functional design, prototyping and field testing, as well as proposing new technical specifications for the list of equipment,

P4.4-686 described the successful operation and maintenance of the Botswana seismological network stations.

O4.4 Network Sustainability and Systems Engineering for CTBT Verification Abstracts of Oral Presentations

O4.4-135 – Operating Temporary Seismic Array During Modernization of IMS Station

Authors: Lukas Menke[1]; Gernot Hartmann[1]
[1]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
Corresponding Author: gernot.hartmann@bgr.de

The PS19 seismic station (GERES) is part of the IMS primary seismic network for verification of the CTBT. The station consists of 25 array elements with an aperture of about 4 km. The modernization of GERES in 2017/2018 implicated a general shutdown of the operation for 18 months, since the intra-array cabling was replaced and new equipment for power supply and data acquisition was installed. However, the absence of this station would have unacceptably decreased the network performance in Europe. Therefore, the operation of a temporary 10-element seismic array guaranteed a continuous data recording with sufficient detectability of seismic signals at this IMS location. The selected configuration has proved successful, that the high performance as is known at GERES could be sustained during the period of construction works. A crucial prerequisite was the high data availability, which was achieved due to reliable set-up of the station equipment. Robust mobile containers housing equipment for power supply, data acquisition and transmission were installed at the individual array elements nearby the vaults, where the seismometers remained at the original position. Especially, the operation of direct methanol fuel cell systems with remote monitoring has proved as technology

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

with high operational reliability.
Promotional text: A long outage of an IMS station due to construction works decreases the network performance. A temporary array with reduced number of elements is a beneficial alternative to sustain the operation of the station. Fuel cell systems are proved to be reliable for the power supply.

O4.4-209 – Advanced Algorithms and Prognostics for Monitoring the Radionuclide Aerosol Sampler/Analyzer (RASA)

Authors: Reynold Suarez[1]; Ian Cameron[1]; James Hayes[1]; Daniel Keller[1]; Ryan Wilson[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: reynold.suarez@pnnl.gov

State of health (SOH) data from radionuclide sensors in the International Monitoring System (IMS) provides critical information about the operating status of stations. Radionuclide systems typically have many sensors that are important indicators of normal operation or system problems. Since there are many IMS stations with radionuclide systems, monitoring them all simultaneously by a single analyst is a challenge. Over the past several years Pacific Northwest National Laboratory (PNNL), in collaboration with General Dynamics, has been developing a status of health monitoring architecture for analyzing SOH data from radionuclide systems of the IMS. The architecture was originally developed to support the Swedish Automatic Unit for Noble gas Acquisition (SAUNA). Recently, the Radionuclide Aerosol Sampler/Analyzer (RASA) was added to the SOH monitoring tool. The tool uses statistical methods such as Exponential Weighted Moving Average (EWMA) and standard deviation techniques to monitor the systems. PNNL is now investigating methods to improve RASA SOH monitoring capability by using advanced algorithms capable of identifying actual failures based on sensor signatures. This research is also seeking to detect and identify the failures as early as possible using advanced prognostic approaches. The results from failure identification techniques and prognostic algorithms will be outlined and presented.
Promotional text: The SOH monitoring methods outlined in this work seek to help IMS operators identify the source of problems early and quickly. This will improve sustainability efforts of the IMS and help both the data quality and availability which are critical to monitoring and verification.

O4.4-528 – Activities to Improve Data Availability by the IMS Maintenance Unit

Author: Nicholas Mascarenhas[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: nmascar1a@gmail.com

Maintaining and improving data availability (DA) of certified IMS stations require the joint efforts of the states hosting International Monitoring System (IMS) stations, local operators and the PTS. Activities that are being undertaken in areas of maintenance, operations, engineering, development, logistics, recapitalization and training across the PTS directly impact the DA and sustainability of the IMS. This paper provides a summary of some key activities undertaken by the IMS Maintenance Unit to improve data availability. These include; equipment standardization, improved hands on technical training, HPGe detector vacuum restoration, improved sparing, improvements to power systems, grounding and lightning protection, infrastructure improvements and equipment upgrades, monitoring HPGe detector SoH and spectral data quality to perform predictive maintenance and improvements to the station environment.
Promotional text: Technical measures undertaken to improve data availability and sustainability of the IMS stations.

P4.4 Network Sustainability and Systems Engineering for CTBT Verification Abstracts of Poster Presentations

P4.4-049 – Upgrade and Recapitalization of Seismic Station AKASG (PS45)

Authors: Viktor Hurynchuk[1]; Marian Jusko[2]; Sergelen Bazarragchaa[2]
[1]*National Space Facilities Control and Test Center, Kyiv, Ukraine*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: gurynchuk@ukr.net

The seismic station AKASG (PS45) is located at the territory of Ukraine. From 2000 to 2002, the station had been being upgraded according to the CTBTO requirements. From 2003 to 2010, the station was operating within IMS, the most important problem in the station data presence during that period was the radio link system, used at the station. From 2010 to 2011, the new modernization project of the station was being developed, which was implemented from 2013 to 2016. In the course of its implementation, the following works were performed: the existed data transferring system from the station elements, which was constructed of both the copper lines and the radio link tools, was replaced into the new one, fiber optic communication lines; all the equipment, installed by SAIC, except of the sensors, was replaced into the new ones; both the power supply system and the lighting protection system were upgraded. The station modernization allowed to increase the data presence from the station elements from 86% in 2015 to 99,9% in 2020. Nowadays, the process of the fiber lines installation at the 8 sites and a new alarm and video surveillance system is being developed.
Promotional text: This annotation is dedicated to the achievements that were obtained during the recapitalization and modernization of the AKASG station in 2013-2020.

P4.4-134 – Modernization of the PS19 Seismic Station

Authors: Torsten Grasse[1]; Gernot Hartmann[1]; Erwin Hinz[1]; Mathias Hoffmann[1]; Marian Jusko[2]; Lukas Menke[1]; Ralf Schönfelder[1]
[1]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: gernot.hartmann@bgr.de

After 25 years of reliable operation, PS19 (GERES) was modernized in 2017/2018. It was the first major upgrade since the station was certified as primary seismic IMS station in 2002. The German NDC operates PS19 remotely. The required data availability is ensured by preventive maintenance twice a year. The station consists of 25 array elements within an aperture of about 4 km. During the modernization, a total of 200 km cables for power supply and data transmission, connecting the array elements with the central facility, were replaced and the infrastructure was refurbished. A new system for overvoltage protection was installed in order to reliably operate the array in future. The GCI between the central facility and the IDC was changed from satellite connection to internet based VPN routing. All GERES GS13 seismometers underwent on-site reference calibration against a set of GS13s tested at CEA, France and SNL, USA in order to validate each seismometer's response against the values configured in the IDC. Data authentication has been successfully transitioned from DSA to ECDSA on both CD1.1 frame and sub-frame level. An additional broadband seismometer was installed for increasing the station's mission capability. PS19 was successfully revalidated in its new configuration.
Promotional text: IMS stations need to be refurbished at the end of physical life of the equipment. The modernization of PS19 represent the complexity of this task for a 25-elements seismic array. State-of-the- art power supply and overvoltage protection guarantees reliable operation in future.

P4.4-139 – Using Data Science for Predictive Maintenance of Noble Gas Systems Within the IMS

Author: Reynold Suarez[1]
[1]*Pacific Northwest National Laboratory (PNNL), Richland, WA, USA*
Corresponding Author: reynold.suarez@pnnl.gov

Analysis of state of health (SOH) data from radionuclide systems can provide information beyond alerts and system diagnostics. Careful analysis of the data can help detect degradation of sensors that may help predict when a failure may occur or the remaining useful life (RUL) of components. In some early work performed by Pacific Northwest National Laboratory (PNNL; US), high-resolution SOH data from the Swedish Automatic Unit for Noble gas Acquisition (SAUNA) and Système de Prélèvement Atmosphérique en Ligne avec l' Ánalyse du Xénon (SPALAX) was analyzed using data-driven approaches with a goal of developing predictive maintenance techniques. This work investigates a hybrid methodology that combines both data-driven and physics-based approaches to more accurately predict system failures. This work also investigates the feasibility of using current available IMS SOH data for predictive analytics as well identification of possible gaps in the data.
Promotional text: The predictive maintenance techniques outlined in this effort will seek to improve sustainability of the IMS network. This aligns with the conference goals of identifying methods to improve monitoring and verification as well as community scientific knowledge exchange of ideas.

P4.4-152 – Station State of Health Monitoring with the Geophysical Monitoring System (GMS)

Author: James Mark Harris[1]
[1]*Sandia National Laboratories (SNL), Albuquerque, NM, USA*
Corresponding Author: mharris@sandia.gov

Sandia National Laboratories is developing the Geophysical Monitoring System (GMS) for modernization of the United States National Data Center waveform processing system, including data acquisition, automated processing, and interactive analysis. The United States is providing the common architecture and processing components of GMS as a contribution-in-kind to accelerate progress on International Data Centre (IDC) Re-engineering. Open source releases of GMS have been made annually since 2018. Recently the GMS project has focused on developing an operational-quality Station State-of-Health (SOH) Monitoring capability, to enhance the ability of system operators to quickly recognize and address station availability and quality issues. This capability was provided to the IDC in the 2020 GMS open source release. The Station SOH Monitoring application has been designed to receive, process, and display SOH information from at least 300 stations using the CD-1.1 protocol, and to meet operational performance, deployment, and reliability specifications. System improvements include using a message-based, reactive software architecture, a Kubernetes containerized deployment platform, and automated system testing capabilities. This presentation describes the GMS Station SOH Monitoring capability, system architecture and design, and deployment and operations.
Promotional text: A new Station SOH Monitoring capability is available in the latest GMS software release provided to the IDC Re-engineering project. This presentation describes this operational capability and improvements to system architecture, design, and deployment.

P4.4-189 – Deployment of Portable Infrasound Sites to Assess Feasibility of Additional Elements, I51 Bermuda, UK

Author: James Robertson[1]
Co-authors: Pierrick Mialle[1]; Jamie Sapsford[2]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
[2]*Bermuda Airport Authority, St George's, Bermuda, UK*
Corresponding Author: james.robertson@ctbto.org

IMS infrasound station I51GB, located on the island of Bermuda in the Atlantic Ocean, was certified in December 2008. The original installation presented many design challenges driven by land availability, island topography and proximity to populous zones. These challenges not only dictated the amount of elements that could be installed, but also the geometry of the station. The array geometry of I51GB is atypical for an IMS infrasound station, comprising of a large-aperture, rectangular four-element array. To add to the uniqueness of the site locations, is the large lagoon that lies directly between all elements. In late 2018, after several incidents of vandalism rendered elements inoperable, the PTS was approached about the feasibility of relocating existing elements to more secure locations, which had become available since the original installation. In September 2019, with cooperation of the Station Operator, the PTS installed two portable infrasound stations in parallel with the existing I51GB elements. Data was collected for roughly 10 months to allow for IMS station site survey requirements and to assess, whether the additional elements benefit station infrasound event detection capabilities. Results from the successful site survey are summarized in this poster.

Promotional text: In 2019, the PTS installed two portable infrasound stations in parallel with the existing I51GB elements. Data was collected for 10 months to allow to assess whether the additional elements benefit station infrasound event detection capabilities.

P4.4-257 – Structure of Testing Technology Programme for On-Site Inspection Equipment

Author: Remi Colbalchini[1]
Co-author: Gregor Malich[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: remi.colbalchini@ctbto.org

The Preparatory Commission is tasked to make all necessary preparations, in fulfilling the requirements of the Treaty and its Protocol, for the support of on-site inspections (OSIs) from the entry into force of the Treaty. The OSI Technology Testing Programme (TTP) is meant to support these preparations. The specific challenges and the unique nature of an inspection is making the synergy between equipment, infrastructure, human resources and procedures very important. The TTP is addressing this synergy through the implementation of a continuous and interrelated development process. Also, the structure of the programme has been designed to formalize the processes in place by describing expected inputs and outputs. From the definition of user requirements, functional design, prototyping to field testing, and propositions of new technical specifications for the list of equipment, the poster will present the different development phases. The iterative and incremental approach will be exposed with concrete examples. They also show that the OSI capabilities must remain suitable and fit for purpose as technology evolves and innovations emerge. Hence, they must be subject to ongoing review with constant attention to their availability and appropriateness which is being considered in the OSI TTP.

Promotional text: The poster intends to support the exchange of knowledge and ideas between the CTBTO and the broader scientific community. Systems Engineering methods are here used in a nuclear test monitoring and verification improvement context.

P4.4-276 – The Sustainment of the IMS Hydrophone Hydroacoustic Network of the CTBT

Author: Georgios Haralabus[1]
Co-authors: Jerry Stanley[1]; Mario Zampolli[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: georgios.haralabus@ctbto.org

Hydroacoustics is the only verification technology of the International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) to be fully certified. Five T-phase stations and six hydrophone-based hydroacoustic stations monitor the world oceans 24/7 for signs of nuclear explosions. Hydrophone stations comprise triplets of underwater microphones, called hydrophones, suspended hundreds of meters below the sea surface and cabled to shore with electro-optical cables, providing near real-time hydroacoustic data to the International Data Centre in Vienna, Austria. Installing the six hydrophone-based hydroacoustic stations in some of the most remote places on the planet constituted a major engineering accomplishment – sustaining or repairing them turns out to be equally, if not more, challenging. Failure causes include natural phenomena, such as underwater landslides which damage underwater segments of cables, degradation of cable protective material in the near-shore areas, and obsolescence or malfunctioning of shore equipment. This poster summarizes the on-going sustainment projects of the IMS hydrophone hydroacoustic network though re-establishment solutions of damaged sections, risk mitigation studies and external aggression protective measures, innovative modular solutions for easy of repair of underwater components and enhanced resilience together with protective measures for onshore electronics.

Promotional text: The certification of all the IMS hydroacoustic stations constitutes a major engineering accomplishment. The sustainment of this network turns out to be equally, if not more, challenging. This poster summarizes all the on-going projects to achieve resilience in hydroacoustics.

P4.4-382 – RASA Revalidation Improvements Using the Rig for Automated Flow Testing (RAFT) System

Author: Gregory Michael Kline[1]
[1]*General Dynamics Mission Systems (GDMS), Chantilly, VA, USA*
Corresponding Author: greg.kline@gd-ms.com

Expanding upon flow analysis efforts presented in SnT 2019, General Dynamics Mission Systems (GDMS) has developed a field deployable system to validate the performance of mass flow meters at International Monitoring System (IMS) radionuclide stations with Radionuclide Aerosol Sampler/ Analyzer (RASA) systems. The Rig for Automated Flow Testing (RAFT) system can validate the factory calibrations of the Sierra 620S mass flow meters, characterize the RASA ductwork's impacts to flow-rate measurements at various operating ranges, and perform flow validation measurements in line with CTBT certification/re-validation procedures for particulate systems. The RAFT system collects and compares measurements from the Sierra 620S flow meter, the RASA system, and the Senya VM700 flow meter in near real-time, minimizing testing errors from manual data acquisition. Using the RAFT system, GDMS can characterize station specific duct work configurations to minimize air volume measurement deviations between the RASA and the Senya VM700 flow meter.

Promotional text: The RAFT system is designed to optimize the flow rate certification efforts for RASA systems. In addition, the RAFT system allows users to field validate existing flow meter installations to ensure they continue to meet CTBT requirements. This effort aligns with Theme 4.2.

P4.4-664 – NORSAR Station Operations and State of Health Monitoring

Authors: Jon Magnus Christensen[1]; Morten Sickel[1]
[1]*Norwegian Seismic Array (NORSAR), Kjeller, Norway*
Corresponding Authors: morten@norsar.no, jon@norsar.no

NORSAR is the Norwegian National Data Centre (NDC) and operates six stations of the International Monitoring System. These are the primary seismic arrays NOA/PS27, ARCES/PS28, the auxiliary seismic array SPITS/AS72, the auxiliary single seismic station JMIC/AS73, the infrasound array IS37 and the radionuclide station RN49. It is crucial to have a good overview of the state of the various components of the stations. NORSAR has since fall 2018 been developing and using a system based on Nagios, PostgreSQL and Grafana to monitor and log uptime and state of health of our installations and processes.

Promotional text: This presentation will give an overview of NORSARs field installations and station operation. Emphasis will be on the how we have set up the new SoH monitoring system and lessons learned so far.

P4.4-686 – Successful Operation and Maintenance of the Botswana Seismological Network (BSN) Stations Including Lessons Learned from the COVID-19 Pandemic Crisis

Author: Joseph Maritinkole[1]
Co-authors: Motsamai Tarzan Kwadiba[1]; Onkgopotse Ntibinyane[2]; Arie Van Wettum[3]
[1]*Botswana Geoscience Institute, Lobatse, Botswana*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
[3]*Utrecht University, The Netherlands*
Corresponding Author: jrmaritinkole@gmail.com

Botswana Seismological Network (BSN) have deployed a countrywide state-of-the-art network of 21 autonomously recording broadband stations. The sensors deployed in the BSN are the Streckeisen and the Nanometrics Trillium 120. A relatively low cost in-house developed NARS Dataloggers developed by the seismology group and the Instrumental group of the Physics department of Utrecht University is used in the BSN together with the new de facto standard Centaur Digital Recorders developed by Nanometrics. For timing the NARS Datalogger uses the Trimble Acutime Gold GPS smart antenna. The BSN is powered by solar energy with the use of a smart charge controller that regulates power. Mobile network communication systems are used to provide continuous remote access. This communication system allows us to connect to the stations remotely via SSH, SFTP and VNC to do remote maintenance, upgrades and to check for the state of health of the stations (SOH). Remote Access to the stations and the use of automated scripts is our new norm of getting the SOH, downloading data and managing most of the routine processes during this Covid-19 crisis. The BSN stations are integrated by Seiscomp3 with the IMS and regional stations to improve location of local and regional earthquakes.

Promotional text: The Abstracts shares ideas with other NDC's how we operate and maintain our network stations. The Abstract is also open to improvements and changes after learning from other Institutions.

T4.5 Resilience of the CTBT Monitoring Regime, Including Lessons Learned from the COVID-19 Pandemic

The global pandemic that began in early 2020 has put a substantial amount of strain on many systems, with the CTBT monitoring regime being no exception. At the same time, the crisis has proved to be a significant and valuable resilience test that examined the functioning of all systems under considerable stress of different kinds, especially lockdowns and travel restrictions. Various aspects of this issue were addressed under this topic.

Scope

- Understanding the global impact and consequences of the COVID-19 pandemic on the operation and sustainment of the IMS.
- Discussing how station operators, network operators and NDC institutions responded to the situation to mitigate the impact of the pandemic and ensure continuous operation and sustainability of the IMS.
- Learning from the lessons of this exceptional worldwide situation and focusing on how to prepare for future network operational challenges, including increasing the use of remote teleconsulting, improving sparing policies and developing and implementing remote monitoring tools.

Sessions

Five time slots on three different days of SnT2021 were dedicated to Topic 4.5:

- Tuesday, 29 June, 11:30-12:30. Special Event 1, with seven online presentations focusing on station operator and NDC experience

- Tuesday, 29 June, 17:15-18:15. Special Event 2, with six online presentations focusing on station operator and NDC experience
- Wednesday, 30 June, 11:00-12:15. Oral Presentation Session, with four online presentations focusing on large network operations during the COVID-19 pandemic
- Wednesday, 30 June, 13:15-14:15. Panel discussion, comprising an online discussion with five panellists
- Friday, 2 July, 9:00-12:00. Poster Session, with 30 online poster presentations

The two Special Events were conducted online, either live or with pre-recorded video material. All discussions and Q&A sessions were live. The two events were held during morning and evening time slots on the same day to allow for participation from different time zones.

Highlights

Oral Presentation Session

Convener: Hideaki Komiyama[1]
Q&A: Mario Villagrán-Herrera[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*

Four online oral presentations were given, focusing on large network operations during the COVID-19 pandemic.

O4.5-192
Performance of the Global Seismographic Network (GSN) During COVID: Challenges and Opportunities

Speaker: Katrin Hafner[1]
[1]*Incorporated Research Institutions for Seismology (IRIS), Washington, USA*

O4.5-192 reviewed the impact of the COVID-19 pandemic on operation of the Global Seismographic Network. Fifty GSN stations also serve as auxiliary seismic stations of the IMS. The stations operate autonomously for long periods of time. Examples of maintenance and repair were provided to show the impact of these activities on data availability. The COVID-19 pandemic limited travel by both local station operators and field engineers. Overall network uptime since January 2020 was 87 per cent, down from 88.7 per cent in 2019. Planned equipment upgrades and preventative maintenance were postponed, and teleconsulting by remote field engineers with local operators increased as a result of the pandemic.

O4.5-385
Maintaining Operational Capability During COVID-19

Speaker: Noor Al-Alami[1]; Rada Hong[1]
[1]*General Dynamics Mission Systems (GDMS), Chantilly, VA, USA*

O4.5-385 described how General Dynamics Mission Systems (GDMS) overcame challenges and implemented innovative strategies to maintain IMS requirements during the COVID-19 pandemic. GDMS focused on five areas: (1) on-site spares, (2) enhanced training material, (3) refined quality assurance processes, (4) development of remote preventive maintenance and (5) the health and well-being of team members. GDMS launched remote training curricula to further local operator maintenance capabilities and implemented video procedures to enhance troubleshooting effectiveness. In the area of preventive maintenance, GDMS ensured team member safety and well-being during daily operations through shift scheduling and video communication methods. Seminars and workshops were held regularly in addition to other efforts to advance inter-team knowledge and create a more efficient work structure.

O4.5-479
Seismic Monitoring in Canada During COVID-19

Speaker: David McCormack[1]
[1]*Natural Resources Canada, Ottawa, ON, Canada*

O4.5-479 described the standard pre-COVID mode of operations for the Canadian National Seismograph Network, a large continental-scale monitoring network, and for the associated IMS stations in Canada. The evolution of the operational status was discussed, including the methods that were found to be suitable and unsuitable to responding to the challenges and constraints of the COVID-19 situation in Canada. Over last several decades, seismic monitoring operations in Canada were driven largely by considerations of resilience and cost-effectiveness. These were refined on the basis of the lessons learned during the novel influenza A (H1N1) pandemic. This previous experience was helpful and resulted in the effective functioning of the system under COVID-19 lockdown conditions.

O4.5-710
Operation of the IMS Network During the COVID-19 Pandemic: Challenges and Solutions

Speaker: Thomas Ludwig Hoffmann[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*

O4.5-710 described the challenges and solutions implemented by the PTS for maintaining the operation of the IMS network during the COVID-19 pandemic. The COPC is responsible for supervision and coordination of the IMS network operations and providing assistance to ensure proper functioning of IMS facilities. Station operators are responsible for the operation of the IMS facilities, in accordance with the Operational Manuals. The global COVID-19 pandemic has brought about numerous unprecedented challenges for the operation of the IMS network. Station operators have faced logistical problems, increased shipping times for spare parts, severe travel limitations, difficulties in the shipment of radionuclide samples for quality assurance/quality control (QA/QC), delays in scheduled station calibrations and unstable communications links. Monitoring tools allowed the COPC to carry out comprehensive analyses of the network to provide practical solutions to station operators. Continuous communication, availability and flexibility in supporting station operators were key to managing the network.

Panel Discussion: Lessons Learned from the COVID-19 Pandemic Crisis as a Resilience Test of the CTBT Monitoring Regime

Panel J02 explored the impacts of the COVID-19 pandemic on the establishment, operation, maintenance and sustainment of the IMS monitoring network, as well as the measures that were taken to ensure continuous data availability and timely delivery of monitoring products. Lessons learned, possible follow-up steps and measures to ensure a sustainable and resilient monitoring regime into the future were also discussed, with perspectives provided from station operators, NDCs and organizations with operational field experience.

Moderators: Stefka Stefanova[1], Thomas Ludwig Hoffmann[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*

Panellists: Katrin Hafner[1]; David McCormack[2]; Paola Garcia[3]; Alexey Anichenko[4]; David Hardmann[5]
[1]*Incorporated Research Institutions for Seismology (IRIS), USA*
[2]*Natural Resources Canada, Canada*
[3]*Comisión Chilena de Energía Nuclear (CCHEN), Chile*
[4]*International Atomic Energy Agency (IAEA), Austria*
[5]*Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), Australia*

Panel Objectives

The objectives of this online panel discussion were:

- To identify, assess and analyse the impacts of the COVID-19 pandemic on the operation, maintenance and sustainment of the IMS network;
- To identify and discuss possible responses that help mitigate impacts on network performance and help address the situation in the short and long terms;
- Based on the lessons learned, to contribute to a more resilient and sustainable monitoring network;
- To propose follow-up steps and measures to ensure a sustainable and resilient monitoring regime.

Main Questions

1. *What were the global impacts and consequences of the COVID-19 pandemic on the operation and sustainment of the IMS monitoring network?*
   David Hardmann identified four key points with regard to the global impact and consequences of the pandemic on the IMS: (1) travel restrictions, (2) site visits, (3) relationships and (4) extra workload. Generally, there were fewer COVID-19 cases in Australia compared with other countries. However, travel was difficult, the country was isolated and external contractors could not enter the country. More work needed to be done on a local basis, and some Pacific and Antarctic locations could not be reached. Shipping was also limited, adding more hurdles. Strong relationships with local station operators were essential to keeping stations up and running. In general, a higher workload was noticed on all sides. A need for new communication channels and remote training was brought forward.

2. *How did station operators/NDC institutions respond to mitigate the pandemic impact and ensure continuous operation and sustainability of the network?*
   Paola Garcia reported that there were seven Chilean IMS stations that needed to be in operation during the pandemic. Chile was hard hit by COVID-19, with more than 9000 infections per day, leading to a full lockdown. On the positive side, it was noted that the station operators live at the site locations. Nonetheless, the logistical aspects of operation and maintenance were complicated owing to shipping and travel restrictions (especially for stations located on islands), difficulties with customs, and infections of station operators. Funding procedures helped overcome difficult situations.

3. *How did other organizations and networks help to mitigate pandemic impacts?*
   Alexey Anichenko reported that the impacts of COVID-19 on IAEA operations were mainly due to travel restrictions and closed borders. Field activities were restricted, so the implementation plan for each country had to be adjusted. The main problem was that restrictions changed frequently, which required close cooperation with countries. A strong collaborative effort was required, and the length of missions increased, as did the cost of travel. Logistics and quarantine requirements were considered, and a charter aircraft was used for the first time to allow for inspections. More investment was made in remote monitoring capabilities. PCR tests for COVID-19 infection were carried out by the Vienna International Centre Medical Service, and additional personnel were employed to overcome the additional workload.

4. *What are the lessons learned from this exceptional worldwide situation?*
   Katrin Hafner reported about travel restrictions, which affected the maintenance of stations. However, it was noted that data availability was only 1 per cent lower than before the pandemic. For seismic stations, borehole sensors were more affected than ground based sensors. New technology and remote troubleshooting were used instead of on-site interaction. Remote training and good sparing logistics helped to keep the equipment operational. In some cases, even local collaborators were not able to travel. The lessons learned from the pandemic included (1) improved design as remote stations (e.g. learn from Mars missions), (2) thorough equipment testing before use, (3) remotely controllable equipment and (4) consistent replicable designs.

5. *What precautionary measures can be introduced to prepare for future network operation challenges?*
   David McCormack reminded the audience that in a few years we might forget the "bad dream" of the pandemic. Therefore it is important to carefully document the lessons now. Using the example of Canada, which has remote stations where access may not be possible during many months due to weather conditions, he pointed out that it is better to build fewer stations of high quality than vast networks with as many sensors as possible. In addition, supply chains are often very tight, which is opposed to the concept of a resilient system. There is a trade-off between efficiency and resilience, with spare parts and simplicity of station design playing an important role in resilience. The audience was reminded that the world today lives in dependency of the GNSS system, where the question of resilience is also a major consideration. The importance of reliable weather forecasting to predict possible impacts on the GNSS system was also noted.

Special Events

The COVID-19 pandemic was a major topic of interest for SnT2021. As a global pandemic, the crisis served as a resilience test for many systems, in particular for the monitoring system of the CTBTO, which relies on continuous data gathering, transmission and analysis. The objective of this series of two special events was to share pertinent case histories and lessons learned in relation to the operation and maintenance of IMS stations, station upgrades and logistics challenges faced by IMS station operators and the PTS as a result of restrictions imposed by COVID-19.

Special Event 1

Discussions during Special Event 1 (M1) focused on (1) the steps taken to ensure operation and maintenance activities for optimal performance of IMS stations IS32 and PS24 (Kenya) despite COVID-19 restrictions, (2) how COVID-19 limitations and restrictions were overcome during the upgrading of five auxiliary seismic stations in Japan, (3) cooperation between the Japan Atomic Energy Agency (JAEA), the PTS, local radionuclide station operators and the manufacturers of the RASA and SAUNA systems at RN37 and RN38 (Japan) to overcome operation and maintenance challenges resulting from COVID-19 restrictions, (4) the timeline of active COVID-19 cases at infrasound station IS42 (Portugal), and the related constraints and actions taken, with PTS support, to guarantee the mission capability of the station, (5) a brief review of interventions by the OSI Training Section to mitigate the loss of on-site technical training and achieve and maintain true blended learning during and after COVID-19 and (6) examples of logistics and maintenance cases that could have affected IMS data availability and the contingency measures that were implemented.

Moderator: Thomas Ludwig Hoffmann[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*

Participants: Josphat Kyalo Mulwa[1]; Ryohei Emura[2]; Yutaka Tomita[3]; Nicolau Wallenstein[4]; Franz Ontal[5]; Mårten Kihlström[6]
[1]*University of Nairobi, Kenya*
[2]*Japan Weather Association (JWA), Japan*
[3]*Japan Atomic Energy Agency (JAEA), Japan*
[4]*University of Azores, Portugal*
[5]*CTBTO Provisional Technical Secretariat, OSI Division*
[6]*CTBTO Provisional Technical Secretariat, IMS Division*

Special Event 2

Discussions during Special Event 2 (M2) focused on (1) how INPRES, Argentina, was able to continue providing its essential services during the COVID-19 pandemic and how face-to-face work and the use of software for teleworking and new work standards affected some station metrics at seismic station PS1, (2) how COVID-19 restrictions affected the operation and maintenance of the IMS infrasound and radionuclide stations operated in Argentina by ARN, (3) the technical and logistical challenges faced and overcome by INOCAR, Ecuador, while operating and maintaining IS20 and RN24 in Galapagos during the COVID-19 pandemic, (4) how technical, environmental, logistical and administrative challenges at infrasound station IS35 (Namibia) in conjunction with COVID-19 lockdowns were overcome to bring the station back to life and return it to mission capability and (5) how restrictions imposed by the COVID-19 pandemic affected the resolution of operational issues with impacts on timely data availability and data quality, together with contingency measures employed.

Moderator: Stefka Stefanova[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*

Participants: Juan Pablo Aguilar[1]; Jorge Perez/Fernando Villacis[2]; Nortin Titus[3]; Thomas Hoffmann[4]
[1]*Instituto Nacional de Prevención Sísmica (INPRES), Argentina*
[2]*Oceanographic Research Institute of the Ecuadorian Navy (INOCAR), Ecuador*
[3]*Ministry of Mines and Energy, Namibia*
[4]*CTBTO Provisional Technical Secretariat, IDC Division*

Main Lessons Learned

- Remote operation of networks is workable and can even be efficient; however, good local support is essential for station maintenance.
- Improving capabilities for remote maintenance and troubleshooting is crucial for the efficient operation and maintenance of stations.
- Local station support is critical for troubleshooting and repairs. Good training of local support staff is essential and substantially reduces travel requirements.
- Developing and implementing reliable communications with local operators/station operators and all parties involved in the operation and maintenance of IMS stations is of major importance. A more flexible approach to communications using different channels is helpful.
- Resilient stations need robustness, including high quality sensors, local data storage capabilities and minimum power requirements.
- Good spare parts logistics is the basis of efficient maintenance. This includes having remote spares depots and hot swappable components, as well as thorough pre-testing of spares.
- Preventive maintenance visits and regionalized operation (e.g. in regions of extreme climate) reduce downtime and loss of data availability.
- Remote training, e-learning and troubleshooting videos can be used to overcome travel restrictions.

- The COVID-19 pandemic provided station and network operators as well as the PTS with an opportunity to test their readiness to respond to network-side limitations and restrictions. Many lessons have been learned from this and many solutions have been, or are being, implemented as a result of the crisis.

Poster Session

P4.5-038 described how, during the COVID-19 lockdown, the control of movement and the reduced civil activities in the area of Brazil where IMS infrasound station IS9 is located resulted in a reduced level of acoustic and seismic background noise. Data from IS9 were analysed, and several new sources of infrasound signals were identified.

P4.5-202 described how the emergency rules imposed during the COVID-19 pandemic were reflected in the operational activities of the NDC of Kazakhstan. To avoid the suspension of data acquisition and transmission processes and to continue data processing and the compilation of seismic bulletins, a rearrangement of the operations centre was needed. Starting in 2018, the gradual transfer of the NDC to virtual mode of operation was accelerated, and by 2020 almost all servers were operating through the Proxmox Virtual Environment with a web interface, allowing a rapid switch to remote operation, analysis and operation of equipment and software.

P4.5-204 discussed lockdown measures in Thailand as a result of the COVID-19 pandemic and the associated reduction of human-made ground vibration. Seismic signals were analysed and presented, as well as a case study from BKSI earthquake monitoring station.

P4.5-244 illustrated how all daily work tasks were carried out remotely through phone calls, email, text messaging and videoconferences after the facilities of Universidad Nacional de Costa Rica were closed under COVID-19 pandemic restrictions. Tasks included clearing customs equipment sent by the international GCI supplier, communicating with the local GCI provider, communications with personnel at the site and videoconferencing with participants of the 2019 CTBTO Infrasound Workshop in Costa Rica. Visits to the station were arranged in the event of technical problems that could not be solved remotely. All described measures have made the work efficient and smooth, ensuring that transmission of seismic data to the IDC is maintained without interruption.

P4.5-252 focused on power supply problems at IMS seismic station PS24 (Kenya), including how these issues were resolved during periods of restricted movement as a result of the COVID-19 pandemic and the steps taken to ensure that operations and maintenance activities were carried out for optimal performance of the seismic station.

P4.5-328 discussed the technical and human constraints in relation to remote work at IMS stations in Bolivia and the activities that were conducted remotely to sustain the operations and maintenance and the state of health for critical systems, such as real time data acquisition, data authentication, and continuous energy supply and data transmission. A web-scraping tool was developed, ensembled with optical character recognition allowing to write simple log files sent by email to be reviewed by station operators in near real time. The tool was preserved as a main tool for routine work at the stations.

P4.5-333 presented improvements in the daily use of six key operation tools to oversee and manage the operation of the IMS network and illustrated how the PTS centralized monitoring tools, the monitoring capabilities for station operators with a large number of stations, the station operator tools for a single or a small number of stations, and the SSI at IMS stations complement each other.

P4.5-342 described the segment of the IMS in the Russian Federation and the activities undertaken by the Special Monitoring Service to ensure certification of radionuclide station RN55, the last of the eight radionuclide stations in the Russian Federation under the CTBT. Other infrastructure projects and work activities carried out during the COVID-19 pandemic in order to maintain a high level of data availability and ensure continuous operation were also presented.

P4.5-349 presented the factors that allowed Geoscience Australia to continue operating IMS stations in Australia and Antarctica with minimal downtime during the COVID-19 pandemic, including robust station design, good working relationships with local operators and remote access to station equipment. Geoscience Australia was able to identify outages, troubleshoot, determine the cause of outages, and in one case rectify the problem and return the element to operation. This was enabled by the ability to monitor station performance remotely to identify the outage and to remotely access station equipment to identify and troubleshoot the issue. Geoscience Australia was also able to engage with the local operator in the vicinity of the station, who had knowledge of the equipment and systems and was able to assist with equipment exchange and perform tests. Good planning, practices and remote technologies helped to ensure that stations remained operational during the crisis.

P4.5-378 demonstrated the General Dynamics Mission Systems (GDMS) concept of operations for IMS stations in the United States, which focuses on robust state of health and remote control capabilities of the particulate and noble gas systems, paired with local operators to monitor the station infrastructure. With COVID-19 limiting travel for engineers to IMS stations, GDMS developed improved remote monitoring such as automated alerts for station environmental and power issues, remote control of station equipment (HVAC units, generators, etc.), and stationary and portable cameras to monitor key equipment. Through this effort, GDMS provided early warning alerts on infrastructure issues, preventing future station outages; reduced the time needed to diagnose station issues, shortening outage durations; and augmented the capabilities of local operators by providing real time remote support during repair efforts.

P4.5-379 illustrated how remote operations enabled the National Institute for Seismic Prevention (INPRES) in Argentina to continue providing essential services during the COVID-19 pandemic and the subsequent quarantine. Duties were carried out using remote and/or virtual platforms, all of which were managed by the use of the Electronic Document Management System (GDE), an integrated system for labelling, numbering, monitoring and recording of all actions and records of the Public Administration, based on remote digital signature or cloud based public key infrastructure (PKI) technology. The physical maintenance of the seismic stations remained on standby, and preventive measures were followed once the lockdown measures were eased.

P4.5-409 showed how technology was used to mitigate challenges during the COVID-19 pandemic, specifically to ensure that nuclear non-proliferation practices remained in place. A comparison was made to assess the benefits of blockchain in maintaining continuous reporting in a time of crisis. Blockchain technology, which does not require human contact, paper records or access to specific locations, helped mitigate some of the challenges by ensuring uninterrupted reporting.

P4.5-432 outlined challenges in implementation of the QA/QC programme of the IMS radionuclide network. In particular, challenges experienced by all stakeholders throughout the sample chain of custody and lessons learned were presented. Continuous collaboration and timely communication between station operators, laboratory operators and the PTS were key factors in the continuous implementation of the QA/QC programme.

P4.5-537 discussed the use of cutting edge technology in training activities to enhance the promotion of CTBT verification technologies and presented experience from online capacity building activities during the COVID-19 lockdown. How to minimize the perceived disruption of training activities as well as a case study of the online training method adopted by the PTS capacity building team were presented. Analysis of the results of the case study highlighted timeliness, excellent knowledge and topic delivery as strengths, while Internet interruptions, lack of physical presence and time zone differences were perceived as weaknesses of the online training courses.

P4.5-542 described the challenges encountered and the solutions implemented to maintain operations of radionuclide station RN11 (Brazil) under COVID-19 restrictions in 2020. The impacts of the restrictions on the management and functioning of the station, including limited access to the station, the inability to send or receive shipments, and the cancellation or postponement of technical visits for maintenance of station equipment, were presented.

P4.5-565 presented the measures adopted by the Seismological Observatory in Brazil during quarantine, including different work approaches in relation to communications, organization and planning of research, and the analysis of IMS data and IDC products. The importance of work-life balance was also emphasized.

P4.5-574 highlighted the importance of the global supply chain, from sourcing to delivery of equipment. Higher redundancy to ensure a functioning supply chain, thereby minimizing the loss of station data due to lack of consumables or missing spare parts, was emphasized. The need for fully developed, tested and ready to implement plans for sparing optimization and cross-functional contingency was also underlined, as well as various ways to address possible disruptions to ensure continued establishment and sustainment of the verification system.

P4.5-583 described the solution deployed by the IMS to enable waveform and radionuclide analysts to securely and reliably work from home, without compromising on efficiency. Essentially, the office set-up used at the PTS, including a Linux workstation and dual monitors, was replicated as needed for analysts at their homes.

P4.5-587 presented the constraints, challenges and possible solutions for the successful operation and maintenance of IS42 (Portugal). A timeline showing how operations and maintenance activities were adapted during the pandemic to ensure mission capability, along with the related constraints and actions taken, were discussed.

P4.5-609 shared PTS experience with regard to scheduled calibration activities under COVID-19 pandemic restrictions and described the extent to which planned calibrations in 2020 were adapted to the unprecedented scenario, requiring high level of flexibility by both station operators and PTS staff. Challenges and solutions were presented, and the experience has demonstrated a new level of readiness to perform scheduled calibrations under critical conditions.

P4.5-611 described the technical and management works needed for the initial testing of infrasound station IS1 (Argentina). Challenges arising as a result of the COVID-19 pandemic and the main actions required for the operation of the station were presented.

P4.5-623 presented the challenges at the COPC to address station issues during the COVID-19 pandemic and to maintain the IMS network at a high level of performance. The operations and maintenance limitations at the stations were summarized, followed by a discussion about the daily activities at the COPC, including a comprehensive analysis of station issues through several monitoring tools. Continuous communication and flexibility to support station operators were essential to making progress in troubleshooting under critical conditions.

O4.5 Resilience of the CTBT Monitoring Regime, Including Lessons Learned from the COVID-19 Pandemic Abstracts of Oral Presentations

O4.5-192 – Performance of the Global Seismographic Network (GSN) During COVID: Challenges and Opportunities

Authors: Katrin Hafner[1]; Dave Wilson[2]; Robert Mellors[3]; Pete Davis[3]
[1]*Incorporated Research Institutions for Seismology (IRIS), Washington, USA*
[2]*US Geological Survey, Albuquerque, USA*
[3]*University of California, San Diego, CA, USA*
Corresponding Author: katrin.hafner@iris.edu

We review the impact of the COVID-19 pandemic on Global Seismographic Network (GSN) operations. GSN stations, of which 50 also serve as IMS auxiliary Seismic Stations, have been designed to operate autonomously with very little operator intervention for long periods of time. These design goals have been strenuously tested with the advent of the COVID-19 pandemic, as travel by both local station operators and field engineers has been severely curtailed. We present examples of adaptive maintenance and repair strategies and the impact these have had on data return. Station downtimes are often limited by pre-positioned spares that may be easily swapped for damaged elements. Despite COVID-related impacts, the overall network uptime since January 2020 at 87%, while down from 88.7% in 2019, continues to exceed our funding agencies' data availability metric of 85%. Planned equipment upgrades and preventative maintenance have been postponed, which may affect future system reliability. COVID and the constraints that the disease places on travel have led to increased use of tele-consulting by remote field engineers with local operators, which we anticipate will lead to enhanced local capabilities and improved overall efficiencies.
Promotional text: Network sustainment and resiliency during a global pandemic.

O4.5-385 – Maintaining Operational Capability During COVID-19

Authors: Noor Al-Alami[1]; Rada Hong[1]
[1]*General Dynamics Mission Systems (GDMS), Chantilly, VA, USA*
Corresponding Author: noor.al-alami@gd-ms.com

General Dynamics Mission Systems (GDMS) overcame new challenges and implemented innovative strategies to maintain International Monitoring System (IMS) minimum requirements during the COVID-19 pandemic. GDMS focused on five areas: on-site spares, enhanced training material, refined quality assurance processes, development of remote preventive maintenance, and the health and wellbeing of team members, in order to maintain the resilience of the CTBT monitoring regime. GDMS launched remote training curricula to further local operator maintenance capabilities and implemented video procedures to enhance troubleshooting effectiveness. These remote training opportunities provided GDMS with valuable information regarding the nuances of local conditions and environments in response to the pandemic. GDMS tailored preventive maintenance plans to identify station specific needs to safeguard stations from critical failures. Efforts to secure team member safety and wellbeing in their daily operation through shift-scheduling, instant- and video focused communication methods, and regular seminars and workshops effectively advanced interteam knowledge and created a more efficient work structure while maintaining health and safety

requirements. These measures, while critical in the midst of the COVID-19 pandemic, revealed many lessons learned regarding efficiency, communication, and innovation. GDMS looks forward to continuing implementation after the pandemic in daily operation and unforeseen circumstances.
Promotional text: Innovative strategies and lessons learned from the GDMS COVID-19 pandemic response highlight valuable avenues of continued improvement in order to maintain operational capability during and beyond the pandemic.

O4.5-479 – Seismic Monitoring in Canada During COVID

Author: David McCormack[1]
Co-authors: Allison Bent[1]; Reid van Brabant[1]; Lorne McKee[1]
[1]*Natural Resources Canada, Ottawa, ON, Canada*
Corresponding Author: david.mccormack@canada.ca

We describe the standard pre-COVID mode of operations for the Canadian National Seismograph Network, a large continental-scale monitoring network, and for the associated IMS stations in Canada. We examine how the operational posture has evolve and then discuss the manners in which the posture was found suitable and unsuitable to respond to the challenges and constraints of the COVID-19 situation in Canada. We find that many of the design and operations decisions that have been taken over the last several decades for seismic monitoring operations in Canada, driven largely by considerations of resilience and cost-effectiveness, and further refined after the lessons learned of the H1N1 pandemic, resulted in a system that continued to function effectively under pandemic lockdown conditions. Specific challenges and lessons learned during the first annual cycle of the pandemic are noted.
Promotional text: We describe the specific challenges and lessons learned during the first annual cycle of the pandemic for the Canadian National Seismograph Network, a large continental-scale monitoring network, and for the associated IMS stations in Canada.

O4.5-710 – Operation of the IMS Network During the COVID-19 Pandemic: Challenges and Solutions

Author: Thomas Ludwig Hoffmann[1]
Co-authors: Rizkita Assef Parithusta[1]; Paola Campus[1]; Paolo Tristan Cruz[1]; Petr Ekimov[1]; Michael Guenther[1]; Dongmei Han[1]; Marina Malakhova[1]; Hlompho Malephane[1]; Elisabetta Nava[1]; Marina Nizamska[1]; Rodrigo Exequiel Villarreal[1]; Shaun Kennedy[1]; Mario Villagran-Herrera[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: thomas.hoffmann@ctbto.org

The CTBTO Provisional Technical Secretariat is responsible for supervision and coordination of the IMS network operations, and for providing assistance to assure proper functioning of IMS facilities. Station Operators are responsible for the operation of the IMS facilities, in accordance with the Operational Manuals, while complying with facility specific contracts, agreements and arrangements. The global response to the COVID-19 pandemic has brought about numerous unprecedented challenges or the operation of the IMS network. Station Operators have faced challenges in accessing and operating their facilities during lockdown phases, and logistical problems such as spare parts shipments have increased during elongated periods with severe travel limitations. This presentation will detail on those challenges, including difficulties with visits to IMS stations, RN QA/QC sample shipments, scheduled calibrations, and troubleshooting of unstable communication links. Through several monitoring tools and the COPC Operations Centre, the PTS carries out comprehensive analyses of the network to provide practical solutions to Station Operators. Continuous communication, availability and flexibility in supporting Station Operators are the key to manage such critical conditions. Further enhancements of PTS monitoring tools are under development to support IMS Station Operators in their intent to improve data availability, data quality and data surety.
Promotional text: The presentation highlights operational challenges and solutions during the COVID-19 Pandemic from the IMS/OPS view.

P4.5 Resilience of the CTBT Monitoring Regime, Including Lessons Learned from the COVID-19 Pandemic Abstracts of Poster Presentations

P4.5-038 – Influence of the Reduction of Human Activity Due to the Pandemic in the Identification of Infrasonic Events by I09BR Station

Authors: Brandow Neri[1]; Lucas Barros[1]; Letícia Assunção[1]; Arthur Macêdo[1]; Monica Von Huelsen[1]
[1]*Seismological Observatory of the Brasilia University, Brasilia, Brazil*
Corresponding Author: brandowlee@outlook.com

The analysis of infrasonic data from the I09BR station, installed in the vicinity of the city of Brasilia, Brazil, indicated a significant reduction in the level of local noise during the COVID-19 pandemic, allowing us to identify other sources of signals previously masked by cultural noise. Most infrasound signals recorded at the I09BR array are originated from sources located close to the surface due to mainly urban activity (airport, factories) and also by quarry blasts that can be recorded in two IMS technologies: seismology and infrasound. Government decrees to control the movement of people in cities to contain COVID-19 considerably reduced the noise produced by the city, improving the performance of the infrasonic station in detecting distant mine blasts. In this work, data from the infrasound station I09BR were analyzed, to observe the variation in the pattern of infrasonic detection caused by changes in people's routine due to social distancing measures decreed by the Government.
Promotional text: Due to the continuous analysis of the infrasonic station I09BR data, several detection patterns can be observed. With the social isolation measures on account of the Covid-19 pandemic, there was a variation of these patterns.

P4.5-202 – Operation of Kazakhstan National Data Center (KNDC) under COVID-19 Pandemic

Author: Igor Komarov[1]
Co-authors: Dmitriy Gordiyenko[1]; Natalia Mikhailova[1]; Pavel Ruabenko[1]
[1]*Institute of Geophysical Research, Almaty, Kazakhstan*
Corresponding Author: komarov.i@kndc.kz

In Kazakhstan, for two months of 2020 there was an emergency rule over the whole country. For Almaty, where the KNDC is located, the urban office for coronavirus prohibited the operation of all offices, including the KNDC, movement of people and transport inside the city was limited. During 1-2 days it was necessary to re-arrange the operation of the Center, avoid the suspension of data acquisition and transmission processes, and continue data processing and seismic bulletins compilation. This became possible owing to gradual transfer of KNDC to the technology of virtual operation of servers and work machines started in 2018. By 2020, almost all servers and work machines operated through the Proxmox Virtual Environment with a web-interface. This helped to quickly arrange remote operation of analysts, and control data arrival and the operation of equipment and software. For two months, only one person had access to the office - not a specialist - who was responsible for heating and communications. He communicated with KNDC staff through the WhatsApp application, received instructions and eliminated problems if it was necessary. For two months of this operation with no people, thanks to the well-arranged computer-communication infrastructure there were no failures in work, and all obligations were implemented properly and on time.
Promotional text: The report shows an example of Kazakhstan National Data Center operation during the pandemic period. The uninterrupted operation of the Data Center is the contribution of the country into the non-proliferation regime and control for nuclear tests.

P4.5-204 – Changes in Seismic Levels in Thailand COVID-19 Epidemic Period: Case Study of BKSI Earthquake Monitoring Station

Author: Chartchai Kamanamoon[1]
[1]*Thai Meteorological Department, Bangkok, Thailand*
Corresponding Author: nuengseismotmd@gmail.com

The COVID-19 outbreak began to emerge in late 2019 at the Wuhan mine in China, with a dramatic increase in the number of people diagnosed with the novel coronavirus. This was until March 2020, when a few other countries started to report massive cases. In a world where people interact with each other at work and elsewhere, this resulted in a marked increase in the number of cases due to human-to-human transmission of this virus. Reducing the transmission of the virus is done by maintaining social distance. As the number of people infected with the virus increased, the Thai government had to declare an emergency situation, causing department stores, schools, et cetera to close. Buses and even planes were disrupted to reduce mass gatherings. Except for pharmacies and other basic needs, workshops and heavy equipment usage were also reduced. There was more working from home. The effect of this lockdown has greatly reduced human-induced ground vibration. After the Thai government announced the removal of the lockdown, the ground shake from June 2020 returned to normal. The man-made seismic signals are clear in approximately 0.1 second intervals and can be observed from characteristics of the seismic signal surrounding the seismic monitoring station with PSDPDF.
Promotional text: Changes in seismic levels in Thailand COVID-19 Epidemic Period: Case Study of BKSI Earthquake Monitoring Station.

P4.5-244 – Station Operator and Impact of the COVID-19

Author: Ronnie Quintero[1]
[1]*Observatorio Vulcanologico y Sismologico de Costa Rica (OVSICORI), Costa Rica*
Corresponding Author: rquinter@una.cr

Costa Rica has been impacted by the COVID-19 pandemic during 2019, which has led to the Universidad Nacional de Costa Rica closing its facilities since March and much of the daily work being done virtually. With Costa Rica's NDC located at UNA, the primary work has been done through phone calls, email, whatsapp and videoconferences and rarely in person. Among the work carried out electronically are the procedures for clearing customs equipment sent by GCI international supplier, calls with local GCI provider, conversations with JTS's site housekeeper and videoconference with participants of the 2019 CTBTO Infrasound Workshop in Costa Rica. From the videoconference, was requested a continuation of training courses and perhaps creation of video clips by CTBTO. During the pandemic, a CTBTO video producer was attended personally and pandemic protocols was followed and there was no setback. Trips were also made to the JTS site to review technical problems in it, using for transportation to the site a vehicle donated by CTBTO and therefore avoiding virus transmission using dedicated transport for the work. All the measures taken until now have made the work efficient and smooth and seismic data from JTS continues to flow to the IDC.
Promotional text: How the pandemic caused by COVID-19 had the station operator's work at Costa Rica and how we continue to give the service to JTS station making the data to continue a smooth flow to IDC.

P4.5-252 – Operation and Maintenance of KMBO Primary IMS Seismic Station in the Wake of COVID-19 Pandemic

Author: Josphat Kyalo Mulwa[1]
Co-authors: Norbert Opiyo-Akech[1]; Glenns Etyang[2]
[1]*University of Nairobi, Kenya*
[2]*Permanent Mission of Kenya, Vienna, Austria*
Corresponding Author: josphat_mulwa@yahoo.com

In the wake of Covid-19 pandemic in Kenya, which apparently coincided with the long rain season, KMBO seismic station experienced rampant mains power outages and/or voltage fluctuations. Rainwater dripped into the tunnel and caused short-circuiting and burning of electrical sockets. Compounded with this problem was the fact that GCI UPS and batteries were not supplying back-up power to the GCI equipment as required until the mains power was either back or stable. Additionally, the GCI UPS batteries had been set to very high threshold such that connection is lost whenever the GCI UPS battery capacity drops to 96%. This rather high threshold in the GCI UPS battery capacity led to numerous communication and data outages and gaps with subsequent IRS and outage tickets from PTS and Hughes Network Systems LLC (the PTS GCI contractor) respectively. Operation and Maintenance was worsened by cessation of movement in and out of Nairobi Metropolitan area imposed by the President of the Republic of Kenya on April 6, 2020. During SnT2021, we will present steps taken to ensure operation and maintenance activities for optimal station performance, demonstrate with, case examples, performance of GCI UPS causing the rampant communication outages and how this problem was resolved.
Promotional text: This paper presents the challenges in O&M of the remote IMS KMBO seismic station in the wake Covid-19 pandemic and the steps taken to ensure O&M activities for optimal performance of the seismic station.

P4.5-328 – A Simple Web-Scraping Tool for State of Health Monitoring Within COVID-19 Times

Authors: Gonzalo Antonio Fernandez[1]; Bastien Joly[2]
Co-authors: Felipe Condori[1]; Jonas Balvidieso[1]
[1]*Observatorio San Calixto, La Paz, Bolivia*
[2]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: director@osc.org.bo

The COVID-19 quarantine accelerated remote work (teleworking), especially in terms of operations and maintenance and the state of health (SoH) for critical systems, such as the real time data acquisition, the authentication, the energy supply and transmission. These were the main variables to monitor from home. Being connected 24 hours to Grafana from our houses was not possible, therefore we coded a small web-scraping tool ensembled with optical character recognition to write simple log files sent by email to be reviewed by Station Operator in near real time. After testing the code during the most critical times (May to September, 2020) we decided to preserve as a main tool for our routine, for the future a graphical interface will be designed.
Promotional text: The remote working speed up the digital migration, however in some regional context the homes were not ready having a laptop for each member of family, Revieing the SoH at certain hours automatically helped us a lot.

P4.5-333 – State of Health Monitoring of the IMS Network

Author: Dongmei Han[1]
Co-authors: Elisabetta Nava[1]; Hlompho Malephane[1]; Marina Malakhova[1]; Michael Guenther[1]; Paola Campus[1]; Rizkita Assef Parithusta[1]; Thomas Ludwig Hoffmann[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: dongmei.han@ctbto.org

The IDC Operations Section makes daily use of six key operation tools to oversee and manage the Operation of the IMS network and the communications between the PTS and station operators. Some tools and their features are already available to station operators through Single-Sign-On (SSO). As part of the COVID-19 resilience enhancement, new features and functionalities are under development to facilitate station operators with notifications, monitoring, and troubleshooting of IMS station incidents and communication between PTS and station operators. Different monitoring tools, including the PTS centralized monitoring tools, the monitoring capabilities for station operators with a large number of stations, station operator tools for a single or a small number of stations, and the Station Standard Interface (SSI) at IMS stations, will complement each other. All these tools will make the monitoring of the IMS network more reliable and incident identification and resolution more efficient and thus contribute to achieve as the highest possible overall IMS network data availability, data quality, and data surety.
Promotional text: Improvements on monitoring tools will facilitate IMS station operator in operating and maintaining the IMS stations in a more reliable and efficient manner and thus contribute to achieve as highest possible IMS network data availability, data quality and data surety.

P4.5-342 – Ensuring the Operation of Russian IMS Stations in the Context of a Pandemic of COVID-19

Author: Ilya Mishenin[1]
[1]*Special Monitoring Service (SMS), Ministry of Defence, Moscow, Russian Federation*
Corresponding Author: ilya.a.mishenin@gmail.com

The Russian segment of the International Monitoring System includes more than 20 objects and started functioning more than 10 years ago. Currently, 97% of the stations identified by the CTBT are certified. Maintaining such an extensive network often requires complex decisions and effective planning. For more than a year, the world community has been continuously fighting the new COVID-19 virus. The pandemic affected many people, intervened in all areas of the economy and industries without exception. Despite the widespread changes in global processes, the task of maintaining the verification regime not only does not become less relevant, but on the contrary requires the consolidation of additional forces. In 2020, the specialists of the Special monitoring service (SMS) ensured the certification of the RN55 Norilsk radionuclide station, which became the last of the eight radionuclide stations provided for by the Treaty in the Russian Federation. The joint effective work of the specialists of the PTS and the SMS allowed us to solve the emerging problems in a short time. In addition, at the moment, the SMS provides a number of other infrastructure projects, performs tasks to maintain a high level of data availability, and guarantees the continuous operation of equipment.
Promotional text: The unique experience gained in performing these tasks can be successfully applied by other IMS station operators and participating countries. Within the designated topic, the work of the SMS staff to ensure the functioning of the Russian segment of the IMS will be evaluated.

P4.5-349 – Operation of Seismic, Infrasound and Hydroacoustic Stations in Australia and Antarctica During the COVID-19 Pandemic

Authors: Hugh Glanville[1]; Craig Bugden[1]
[1]*Geoscience Australia, Canberra, Australia*
Corresponding Author: craig.bugden@ga.gov.au

Robust station design, good working relationships with local operators and remote access to station equipment are key factors that allowed Geoscience Australia (GA) to continue operating CTBTO stations in Australia and Antarctica with minimal downtime during the COVID-19 pandemic. Travel restrictions within Australia due to the pandemic resulted in station maintenance only undertaken for one out of five Australian stations between December 2019 and November 2020. Although Australian stations were minimally impacted, GA encountered problems with single elements at two Infrasound arrays. We were able to identify the outages, troubleshoot and determine the cause, and in one case rectify the problem and return the element to operation. This was due to our ability to monitor station performance remotely to identify the outage, and remotely access station equipment to identify and troubleshoot the issue. We were able to engage with the local operator nearby the station with knowledge of the equipment and systems who could assist with equipment exchange and perform tests. With travel restrictions lifting in Australia we are now able to reinstate regular maintenance visits of stations. However good planning, practices and remote technologies assisted in ensuring stations remained operational in Australia during the crisis.

Promotional text: Detailed are challenges encountered in operating CTBTO stations during the COVID-19 Pandemic in Australia and Antarctica. Effective methods of station operation, monitoring and remote access to ensure availability of seismic, infrasound and hydro-acoustic are described.

P4.5-378 – Development of Remote Station Infrastructure Monitoring Tools

Author: Shaun Little[1]
Co-authors: Gregory Michael Kline[1]; Dennis Bustillo[1]
[1]*General Dynamics Mission Systems (GDMS), Chantilly, VA, USA*
Corresponding Author: shaun.little@gd-ms.com

General Dynamics Mission Systems' (GDMS) concept of operations for US International Monitoring System (IMS) stations focuses on robust state of health and remote-control capabilities of the particulate and noble gas systems, paired with local operators to monitor the station infrastructure. However, with COVID-19 limiting travel for engineers to IMS stations, GDMS is improving our remote monitoring capabilities for the station infrastructure to assist our local operators. This monitoring includes automated alerting for station environmental and power issues, remote-control of station equipment (HVAC units, generators, etc.), and stationary and portable cameras to monitor key equipment. Through this effort GDMS looks to provide early warning alerts on infrastructure issues, preventing future station outages. Furthermore, by increasing these remote monitoring capabilities, GDMS can reduce the time needed to diagnose station issues, shortening outage durations. Finally, with video cameras onsite, GDMS looks to augment the capabilities of local operators by providing real-time remote support during repair efforts.

Promotional text: The development of remote station infrastructure monitoring highlights the ways GDMS is adapting to and overcoming the challenges posed by the COVID-19 pandemic. This effort aligns with Theme 4.5 "Resilience of the CTBT Monitoring Regime, Including Lessons Learned from the COVID-19.

P4.5-379 – INPRES Seismic Monitoring During the COVID-19 Pandemic Crisis

Author: Juan Pablo Aguiar[1]
[1]*Instituto Nacional de Prevención Sísmica (INPRES), San Juan, Argentina*
Corresponding Author: juan.pablo.aguiar@gmail.com

The National Institute for Seismic Prevention (INPRES) was able to continue providing its essential services during the COVID-19 pandemic and the subsequent quarantine thanks to remote operations. INPRES' primary mandate is the development of the earthquake-resistant construction regulations and its continuous updating as well as seismic monitoring. During the period of preventive and compulsory social isolation, called ASPO, duties carried out using remote and/or virtual platforms. All of them were managed by the use of the Electronic Document Management System (GDE), an integrated system for labeling, numbering, monitoring and recording of all actions and records of the Public Administration, based on Remote Digital Signature or PKI Cloud, with the database in the Arsat National Data Center. The physical maintenance of the seismic stations during the ASPO period was on standby. Once ASPO is finished and in return to face-to-face activities, preventive measures were followed, such as: personnel temperature monitoring upon entering the Institute, biometric sensing on entry/exit, use of the face mask, the reduction of working hours, avoiding sharing offices and official vehicles for transportation, in addition to those already imposed by government about distancing, PCR test requirements and the closure of the country's borders.

Promotional text: Procedures to carry out the seismic monitoring by the National Institute for Seismic Prevention of Argentina, INPRES, during the COVID-19 pandemic based on Remote Digital Signature, with database in a secure National Data Center.

P4.5-409 – The Importance of Blockchain in Nuclear Verification as a Solution to Reporting Hardships in Times of Crises

Author: Caitlin McLain[1]
[1]*Purdue University Global, Indianapolis, IN, USA*
Corresponding Author: caitlin.mclain97@gmail.com

The COVID-19 pandemic illustrated how the world could shut down overnight and how adaptations need to occur immediately in order to continue the functionality of imperative operations such as those of the CTBTO. Because of the issues brought to light in the COVID-19 pandemic, it is imperative to learn how technology can be used to mitigate the challenges highlighted during the COVID-19 pandemic specifically ensuring nuclear nonproliferation practices remain in place. Utilizing secondary analysis comparison was made on benefits blockchain has in maintaining continuous reporting in a time of crisis. Blockchain is a technology that helps mitigate some of the challenges that arose and became apparent during the COVID-19 crisis by ensuring uninterrupted reporting because it does not require human to human contact, paper records, or access to specific locations. Blockchain technology is not something that is only useful in a pandemic but can be extrapolated to times of war and severe weather or climate crises.

Promotional text: Covid-19 outlined various challenges that can arise in a time of crisis illustrating the importance of having technologies in place that can overcome and operate through those challenges.

P4.5-432 – Radionuclide Particulate Network QA/QC Programme 2020: Challenges and Lessons Learned During the Global COVID-19 Pandemic Crisis

Author: Paolo Tristan Cruz[1]
Co-authors: Rodrigo Exequiel Villarreal[1]; Elisabetta Nava[1]; Dongmei Han[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: paolo.tristan.cruz@ctbto.org

Since 2004, the PTS requests, on a quarterly basis, a random sample from a certified station to be sent to an IMS-certified laboratory for re-analysis as part of its IMS Radionuclide Network QA/QC Program. The global response to contain the SARS-CoV-2 (COVID-19) pandemic in 2020 has brought numerous unprecedented challenges in the implementation of the RN QA/QC Program. This presentation will discuss the challenges experienced by all stakeholders throughout the sample chain-of custody and the lessons learned during the COVID-19 crisis. Continuous collaboration and timely communication between Station Operators, Laboratory Operators, and the PTS are key factors in the continuous implementation of the QA/QC Program amidst current and similar crises in the future.

Promotional text: This presentation will discuss the challenges experienced by all stakeholders throughout the sample chain-of-custody and the lessons learned during implementation of the IMS RN Particulate QA/QC Program 2020 amidst the COVID-19 crisis.

P4.5-537 – Experiences from the CTBTO Online Capacity Building Activities During Covid-19 Lockdown

Authors: Uchenna Onwuhaka Madu[1]; Awwal Bisallah[1]
[1]*Nigeria Atomic Energy Commission, Abuja, Nigeria*
Corresponding Author: uchechi231@gmail.com

The CTBT mandated the PTS to equip State Parties with the prerequisite capacity to monitor compliance to the Treaty. The advent of Covid-19 and its associated lockdown disrupted the capacity building activities of the PTS. To minimize the perceived disruption of training activities, the capacity building team of the CTBTO adopted an online training method. Two online NDC Waveform Training Courses on using SeisComP3 were conducted by the capacity building team on 2-6 November and 23-27 November via the WebEx platform. The two courses had about 27 participants. A SWOT test of the two online training courses was done using a structure questionnaire that was administered randomly to selected participants. An analysis of the results from the study identified timeliness, excellent knowledge and topic delivery as some of the identified strengths while internet interruptions, lack of physical presence and time zone differences were perceived weakness of the online training courses. The experiences gained by the State Parties that participated in the online training will strengthen the deployment of the CTBT verification technologies for civil and scientific purposes. Further funding of the capacity building activities will enhance the ability of more State Parties in the monitoring of compliance with the Treaty.

Promotional text: The use of cutting edge technology in training activities will enhance the promotion of CTBT verification technology.

P4.5-542 – Difficulties and Obstacles to Keeping a Radionuclide Station in Operation in Brazil During 2020

Author: Rocio Reis[1]
[1]*Institute of Radioprotection and Dosimetry, Rio de Janeiro, Brazil*
Corresponding Author: rocio@ird.gov.br

The RN11 radionuclide station is located at the Institute of Radioprotection and Dosimetry, in the city of Rio de Janeiro, Brazil. The country has been severely affected by the pandemic, with millions of people infected and more than 185,000 dead. The different spheres of government sought to manage the effects of this tragic event in different ways, such as instituting rules for social engagement, remote work, blockades, among other initiatives. Many of these laws and

regulations have had adverse effects on the management and functioning of the RN11 station, such as the difficulty of access of team members to the RN11 station building, or the inability to send or receive shipments and also the cancellation or postponement of technical visits to maintenance of station equipment. On the other hand, as the pandemic evolved, the team had to take measures to protect itself from the danger and at the same time try to keep the RN11 station running. The station underwent several events that year, such as the replacement of the X-cooler and various other maintenance. An analysis of these events identifying the positive and negative points and the opportunities for improvement are presented in this article.
Promotional text: To overcome the difficulties during the pandemic, several initiatives were taken and these experiences, when analyzed, should contribute to improve the performance of activities at the station and serve as inspiration for other teams in stations with similar dynamics.

P4.5-565 – Adoption of New Ways of Working During the Pandemic

Authors: Carlos Eduardo Bonfim[1]; Brandow Neri[2]; Lucas Barros[2]; Edson Andrade[3]
[1]*Army Technological Center, Brazil*
[2]*Seismological Observatory, University of Brasilia, Brazil*
[3]*Federal University of Paraiba, Brazil*
Corresponding Author: bonfim.carlos@eb.mil.br

One of the great challenges during the pandemic crisis caused by COVID-19 was to adapt the way of working during the quarantine. Communication, organization and planning were fundamental pillars to manage the activities involving the research and analysis of the IMS data and IDC products. One thing is certain, the tools of organization, management, communication and planning, contributed so that the activities could happen. Thus, facilitating the challenges of working in the home office since it is necessary to divide the time focused on work activities with the distractions of the house. Children who are in homeschooling, the presence of their parents, husband or wife, and even day-to-day functions, such as cooking and washing clothes. This work aims to address the measures adopted by IDQBRN and OBSIS / (their department) for the continuity of activities during the global pandemic caused by COVID-19.
Promotional text: The work aims to contribute presenting the measures adopted by IDQBRN and OBSIS during quarantine in Brazil.

P4.5-574 – Increasing International Monitoring System (IMS) Supply Chain Resilience During COVID-19

Authors: Marten Kihlstrom[1]; Hideaki Komiyama[1]; Nurcan Meral Özel[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: marten.kihlstrom@ctbto.org

The sustainment of the IMS encompasses a global supply chain from sourcing to delivery of equipment. The supply chain is exposed to disruptions caused by the COVID-19 pandemic and measures adopted by countries, resulting in border closures, restrictions in the movement of goods and other logistical constraints. Inevitably the establishment and sustainment of the IMS network is affected. From the outset the PTS recognized the need for higher redundancy to ensure a functioning supply chain to minimize the loss of station data due to lack of consumables or missing spare parts. Levels of critical spare parts at stations were reviewed combining station operator input, known supply chain disruptions, PTS' own experience and knowledge and analytical results from sparing optimization. Where indicated, additional equipment was sent to depots and stations. The availability of transportation possibilities was explored and monitored continuously developing and applying contingency plans to have more than one shipping alternative available. Experience showed the importance of cross-functional contingency plans developed,

tested and ready to implement before a supply chain disruption occurs as it is too late to develop, test and implement such plans at the same time.
Promotional text: The COVID-19 pandemic has implications on all global supply chains - the IMS network is no exception. The PTS is addressing these disruptions in various ways to ensure continued establishment and sustainment of the verification system.

P4.5-583 – Remote Analysis: Empowering Analysts to Work from Home

Authors: Catherine Wambua[1]; Lucas Ferreira[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: catherine.wambua@ctbto.org

Due to the COVID-19 crisis of 2020, most organizations had to re-adapt their working routines, permitting their employees to work remotely instead of at the office. The CTBTO was no exception, in March 2020 and again in November 2020, all CTBTO employees including waveform (SHI) and radionuclide (RN) analysts were mandated to work from home. The challenge that arose for us in IMS/NSS, was preparing a setup fit for SHI and RN analysts to securely work remotely and reliably, without compromising on efficiency. At the office, each analyst is equipped with a Linux workstation, and due to the nature of the analysis software that requires a dual monitor setup, two monitors with a 1920 X 1200 resolution. To meet the reported challenge, this setup had to be replicated at home. This presentation describes the complete solution that was deployed and its dependencies, and the influence it had on the analysts' working routines.
Promotional text: This presentation describes the solution and its dependencies that was deployed by IMS/NSS to enable waveform and radionuclide analysts to securely work from home as a result of the COVID-19 crisis of 2020.

P4.5-587 – IS42: COVID-19 Breakdown Operation and Maintenance Constraints in the Azores Islands

Author: Nicolau Wallenstein[1]
Co-authors: Sandro Matos[1]; Maria do Céu Jesus[1]; Flavio Soares[1]; Arturo Montalvo[1]
[1]*Instituto de Investigação em Vulcanologia e Avaliação de Riscos (IVAR), Azores, Portugal*
Corresponding Author: nicolau.mb.wallenstein@azores.gov.pt

Located on the island of Graciosa, Azores, the infrasound station's (IS42) operation and management (O&M) activities are carried out by two station operators, a local operator and IVAR technical staff. The operation is carried out remotely from the IVAR facilities, located on the São Miguel Island. Inspection and preventive maintenance are carried out at 15-day intervals by the local operator and bimonthly by a station operator. This is performed annually by both operators, IVAR staff and subcontracted companies. Air travel between São Miguel and Graciosa last two hours, including Terceira island. The first COVID-19 active case occurred in the Azores on March 15. On the nine islands with 243 000 inhabitants and initially only one with a limited yet COVID-19 capable health care infrastructure, the Government of the Azores implemented restrictive measures to mitigate the virus propagation and monitored the related epidemiology. The IVAR also implemented restrictive actions in its contingency plan. Those constraints included, among others, closure of public and private services; confinement of visitors and residents; establishment of sanitary fences; suspension of air links, etc. We present here a timeline of the active cases, the related constraints and O&M actions taken, with the PTS support, to guarantee the mission capability of the station.
Promotional text: In a remote archipelago, with limited health system response to the COVID-19, where regional authorities have taken very restrictive measures to mobility and access to IS42 station infrastructures, a timeline shows how O&M activities have been adapted to keep Mission Capability.

P4.5-609 – Scheduled Calibration of IMS Seismic and T-Phase Stations: Challenges and Solutions Within the COVID-19 Pandemic Scenario

Authors: Paola Campus[1]; Riyo Otsuka[1]; Rizkita Assef Parithusta[1]; Hlompho Malephane[1]; Michael Guenther[1]; Marina Malakhova[1]; Yacine Sid Ahmed[1]; Moctar Moumouni Kountche[1]; Sergelen Bazarragchaa[1]
Co-authors: Dongmei Han[1]; Julien Marty[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: paola.campus@ctbto.org

Station calibration activities at IMS Seismic and T-phase IMS Stations aim at fulfilling the requirements defined in the Operational Manual for Seismological and Hydroacoustic Monitoring and the International Exchange of Seismological and Hydroacoustic Data. The 2020 Scheduled Calibration activities have been merged in the unprecedented scenario of the COVID-19 pandemic. The PTS Calibration Team has adopted a high level of flexibility and adaptation during the pandemic, in order to assure the necessary support to Station Operators and achieve the successful completion of the Scheduled Calibration 2020. Examples of the encountered challenges and adopted solutions within the COVID-19 scenario will be provided. The experience has paved the way for preparing a new level of readiness to perform Scheduled Calibration activities under very critical conditions.

Promotional text: Station Operators and the PTS faced new challenges for maintaining the operational standards, including scheduled calibrations, at IMS Stations during the COVID-19 pandemic. This Abstract provides an example of resilience of the CTBT monitoring regime.

P4.5-611 – IS1, Pilcaniyeu, Argentina: Initial Testing Management During the COVID-19 Pandemic

Author: Victor Fontenele Carvalho[1]
Co-author: Juraci De Carvalho[1]
[1]*Enki Projetos de Engenharia, Goiânia, Brazil*
Corresponding Author: juraci-br@hotmail.com

The challenging situation brought about by the new corona virus (COVID-19) required radical actions from governments worldwide in an attempt to slow down the spreading of the virus until a vaccine became available. Lockdowns became a de facto practice to prevent the virus from spreading further by reducing people's circulation. However, such practice had extremely negative effects on people's lives, essential services and the economy. In this context, it would be reasonable to expect that the operation of the IMS network was also impacted. Station IS01-Pilcaniyeu in Argentina is an unmanned station composed of 8 elements. It was built in 2018/2019 and was certified in December 2019. It is currently running under the Initial Testing Agreement. During the pandemic, our team faced several challenges to ensure it remained operational. Overall, the station proved to be robust and did not present any signs of deterioration that required repairs, changes or upgrades. Thus far, it has been operational for almost 100% of Mission Capability during the period. During this presentation, we will discuss the challenges and lessons learned from the management of the IS01-Pilcaniyeu station during the pandemic.

Promotional text: The challenging situation brought about by the new corona virus (COVID-19) required radical actions from governments worldwide to slow down the spreading of the virus. In this context, it would be reasonable to expect that the operation of the IMS network was also impacted.

P4.5-623 – Daily Challenges at the IDC Operation Centre to Address Station Issues During the COVID-19 Pandemic and Maintain the IMS Network at a High Level of Performance

Authors: Rizkita Parithusta Assef[1]; Paola Campus[1]; Michael Guenther[1]; Dongmei Han[1]; Hlompho Malephane[1]; Marina Malakhova[1]

[1]*CTBTO Preparatory Commission, Vienna, Austria*

Corresponding Author: rizkita.assef.parithusta@ctbto.org

Daily challenges at the IDC Operation Center to address Station issues during the COVID-19 pandemic and maintain the IMS network at a high level of performance. The COVID-19 pandemic and the associated public health interventions undertaken to contain it have resulted in widespread and unprecedented social disruption. Station operators are responsible for the operation of the individual International Monitoring System facilities in accordance with the IMS Operational Manual. In this context, station operators faced the new challenge of operating stations during a lockdown or in periods of severe travel restrictions. The restrictions imposed by Governments created limitations to perform the on-site troubleshooting, which forced station operators to maximize their capability to perform remote troubleshooting. The PTS has developed a comprehensive analysis of station issues through several monitoring tools, thus providing solutions that can be implemented by station operators to handle such issues in a timely manner. Continuous communication and flexibility to support station operators is also key to making progress in troubleshooting under critical conditions. The presented results show that this approach can minimize station downtimes and keep the IMS network at a high level of performance, even during a pandemic.

Promotional text: Station Operators and the PTS faced new challenges to handle the incidents to keep the IMS network at a high level of performance during the COVID-19 pandemic. This Abstract provides an example of the resilience of the CTBT monitoring regime.

6.5. Theme 5: CTBT in a Global Context

The CTBTO verification system exists within the broader context of international organizations, global policy making and international collaboration, public awareness and safety. This theme explores lessons learned from other arms control agreements and arrangements and from relationships within a broader context as they relate to the CTBT and nuclear explosion monitoring.

Advances in science and technology can bolster evidence-based policy making, which in turn can reinforce confidence building. This theme explores applications of verification technologies and identifies innovative solutions within the framework of the CTBT as well as other relevant agreements and arrangements.

Apart from their purpose of monitoring and detecting nuclear test explosions, IMS data and IDC products may be made available for scientific use, under confidentiality agreements, through vDEC. IMS data may also be used for civil applications, such as nuclear and radiological emergency preparedness and tsunami early warning systems.

Ensuring that countries and institutions have a robust science–policy interface requires the wide dissemination and appropriate communication of scientific knowledge to both decision makers and the general public. It is therefore important to raise awareness and understanding through a broad range of outreach initiatives and science communication.

T5.1 Science in Policy Discussions and Scientific Lessons Learned from Other Arms Control Agreements and Arrangements

Highlights

P5.1-055 discussed the virtual meetings of the Scientific Advisory Board of the Organisation for the Prohibition of Chemical Weapons (OPCW) during the COVID-19 pandemic. The overall experience was successful, with a very high degree of participation and the possibility to hold a large number of shorter meetings and include contributions from external speakers who under normal circumstances probably would not travel for in-person meetings. P5.1-460 discussed knowledge transfer processes at the OPCW, including interviews and meetings with experts for people who are leaving the organization.

The round table discussion touched upon issues that pertain to the future of the CTBTO. P5.1-067 argued that there is a need to address allegations that activities being carried out are inconsistent with the Treaty (an eight minute video was uploaded to present the case by the author). P5.1-661 discussed the CTBT in relation to the Southeast Asian Nuclear Weapon-Free Zone Treaty (Bangkok Treaty), while P5.1-492 focused on the CTBT in relation to the Treaty on the Prohibition of Nuclear Weapons. P5.1-317 explored the ratification prospects of the CTBT. P5.1-422, which described IMS achievements, was presented by a CYG member.

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

P5.1 Science in Policy Discussions and Scientific Lessons Learned from Other Arms Control Agreements and Arrangements Abstracts of Poster Presentations

P5.1-055 – Resiliency and the OPCW Scientific Advisory Board: Tales of Providing Scientific Advice During a Pandemic

Author: Peter Hotchkiss[1]
[1]*Organisation for the Prohibition of Chemical Weapons (OPCW), The Hague, The Netherlands*
Corresponding Author: peter.hotchkiss@opcw.org

Decision makers serving in policymaking organs of international arms control, disarmament and non-proliferation instruments often consider and review information with significant scientific underpinning. Engagement with scientific communities helps to ensure that an organisation remains abreast of developments in science and technology, and can continue to adapt to emerging challenges and develop capabilities that enhance operational effectiveness. The Organisation for the Prohibition of Chemical Weapons utilizes its Scientific Advisory Board (SAB) to monitor science and technology development of importance to the Chemical Weapons Convention, States Parties, and the OPCW. The SAB has recently, as everyone else, had to adapt to a challenging and changing working environment – one where travel is restricted and communication taxed. We will discuss the SAB's important role in providing scientific advice to the OPCW, States Parties and policymakers and how the SAB has continued its work during the recent Covid-19 pandemic. Necessary adaptations, success stories and lessons learned to providing scientific advice during uncertain times will be shared. The current challenge has given us an opportunity to test our fortitude and build resiliency into our processes, guaranteeing the SAB's efforts and effectiveness moving forward.
Promotional text: Science underpins treaty implementation. Ensuring that science advice is available to policymakers even during challenging and uncertain times, such as during the recent Covid-19 pandemic, requires forethought and remains critical to proper treaty implementation.

P5.1-067 – A New Threat to the CTBT

Author: Edward Ifft[1]
[1]*Hoover Institution, Stanford University, Stanford, USA*
Corresponding Author: emifft@yahoo.com

The CTBT is under a new threat. The 2020 U.S. Compliance Report charges that "Russia has conducted nuclear weapons experiments that have created nuclear yield and are not consistent with the U.S. 'zero-yield' standard," and may also be guilty of a violation of the 1990 Threshold Test Ban Treaty. The Report claims that China may be guilty of similar activities. Similar charges have been circulating in the U.S. for years, but this is the first time a "finding" has been made by the U.S. Intelligence Community. The fact that U.S. charges of non-compliance by Russia resulted in the Trump administration's withdrawal from both the INF Treaty and the Open Skies Treaty indicates that this situation needs to be resolved urgently. No evidence is presented for these charges and the International Monitoring System has not reported any relevant evidence of such activities. This problem has at least three aspects. These are the treaty obligation found in Article I, the obligation found in the Vienna Convention on the Law of Treaties and the voluntary testing moratoria being undertaken by many countries. This issue may recede a bit under President Biden, but still must be cleaned up.
Promotional text: This presentation discusses the charge in the 2020 U.S. Compliance Report that Russia, and perhaps China, are violating obligations related to the CTBT. This poses a serious threat to the CTBT itself. The relevant obligations are discussed, along with possible solutions.

P5.1-317 – Future of Comprehensive Test Ban Treaty and Its Impact on the Non-Proliferation Regime

Author: Mishal Batool[1]
[1]*Fatima Jinnah Women University, Pakistan*
Corresponding Author: beenishaltaf7@gmail.com

The Comprehensive Test Ban Treaty (CTBT) has not entered into force, due to the non-ratification of 44 specific states. It is still not on the top priority of NWS, especially the US; therefore one should not expect it to enter into force in the near future. It still needs to be signed and ratified by all major powers. The Treaty has been called a 'dead horse' by several international scholars as well as the community worldwide. The prospects of the remaining states signing the CTBT have been fading constantly due to the consideration that the US will not ratify it even it endorsed in its US Nuclear Posture Review 2018. However, this paper also highlights how most of the world's advance technological stockpiles were developed with the assistance of computer models simulation nuclear tests. Likewise, it has tried to review the positions held by the two nuclear South Asian countries on the CTBT as well.
Promotional text: Since none of the theme's sub-topics has mentioned its impact on other arms control and non proliferation regime, the paper will outline its future standings in the complex environment where no other state is taking any substantial measures for its ratification.

P5.1-422 – 25 Years of CTBTO: Progress with Verification Technologies and Looking Towards the Future 25 Years and Beyond

Author: Courage Tatenda Chirobe[1]
[1]*CTBTO Youth Group*
Corresponding Author: couragetatenda@yahoo.com

A total of 10 nuclear tests have been conducted since the organization of the CTBTO in 1996 and the International Monitoring System (IMS) has played a key role in the detection of 6 of these tests, all of which were conducted by the Democratic People's Republic of Korea (DPRK). The first one was on October 9 2006 which was detected by 22 stations and had a recorded local magnitude 4.1. The second test, conducted on May 25 2009 was detected by 61 stations with magnitude 4.52. The third test conducted on February 12, 2013, with magnitude 4.9 was detected by 96 stations, two of them infrasound. Radioactivity consistent with this test was later detected at radionuclide stations in Japan and Russia. The fourth test conducted on January 16 2016 was initially detected by 27 stations and the fifth test conducted on September 9 later that year was detected by over 100 stations with a magnitude 5.1. 38 stations contributed to the technical analysis of the September 3 2017 test whose magnitude was determined to be 6.1. This serves as evidence that the IMS has been effective in the detection of nuclear tests conducted during this period.
Promotional text: The presentation aims to celebrate the achievements made by the IMS in the last 25 years as well as highlight some of the goals of the verification regime looking into the future.

P5.1-460 – Implementing Knowledge Transfer Processes: Lessons Learned from an Application in the OPCW

Authors: Marta Galindo Arranz[1]; Marine Constant[1]; Zaven Hakopov[1]1; Imededdine Hassen[1]
[1]*Organisation for the Prohibition of Chemical Weapons (OPCW), The Hague, The Netherlands*
Corresponding Author: galindoarranz@gmail.com

The Chemical Weapons Convention is an international disarmament treaty intended to exclude completely the possibility of the use of chemical weapons. The Convention prohibits the development, production, acquisition, stockpiling, retention, transfer or use of chemical weapons, and provides for the destruction of existing stockpiles. The Verification division (VER) provides support to the States Parties by technically

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

assess compliance with their obligations and by implementing a credible verification regime. VER has done a project to identify improvements on its knowledge transfer processes. The project evaluate VER knowledge transfer activities and tools, identify gaps and propose corrective actions. The study presents lesson learned from knowledge transfer exercises and practical cases where the implementation of knowledge transfer processes results in improvement of operational processes efficiency. This is fundamental for the sustainability of the operational processes in organization with high turnover of expertise.

Promotional text: The project highlight the importance of knowledge transfer processes and how a good implementation improve the efficiency of the operational process. This is fundamental for the sustainability of the operational processes in organization with high turnover of expertise.

P5.1-492 – The Need for the Comprehensive Nuclear-Test-Ban Treaty to Enter into Force and Its Relationship with the Treaty on the Prohibition of Nuclear Weapons

Author: Lucía Centellas[1]
[1]*International Campaign to Abolish Nuclear Weapons (ICAN), Bolivia*
Corresponding Author: centellas.lucia@gmail.com

The risk of deliberate or accidental use of nuclear weapons has increased in a global context that is in itself challenging for multilateralism. The Comprehensive Nuclear-Test-Ban Treaty (CTBT) and its verification regime, despite not having entered into force, have contributed significantly to protecting humanity from the profoundly damaging environment and health consequences of nuclear tests and will continue to be a fundamental pillar in the nuclear disarmament and nonproliferation regime. The entry into force of the Treaty on the Prohibition of Nuclear Weapons (TPNW) in January 2021, highlights the need for the Annex 2 States to ratify the CTBT. The TPNW recognizes the relevance of CTBT and contains commitments to assist victims of the testing or use of nuclear weapons or other nuclear explosive devices, a new type of obligation that relies in part on the CTBTO international monitoring system. Therefore, based on a review of the relevant literature and interviews with experts, the main objective of this review is to identify and characterize the potential areas of cooperation between the CTBT and the TPNW.

Promotional text: This proposal seeks to emphasize the importance of the entry into force of the CTBT, and the relevance of the international verification system, for compliance with some of the provisions of the TPAN and other instruments of the nuclear disarmament and non-proliferation regime.

P5.1-661 – Science and Policy: Bangkok Treaty from a Scientific Point of View

Authors: Almanzo Arjuna[1]; Yessika Natalia Chelsea[1]; Diva Jati Kanaya[1]; Bagus Suryo Leksono[1]
Co-author: Deandra Madeena Moerdaning[2]
[1]*Universitas Gadjah Mada, Indonesia*
[2]*The ASEAN Secretariat, Indonesia*
Corresponding Author: almanzo.arjuna@mail.ugm.ac.id

Legally-binding nuclear-test ban is essential to ensure peace and security for all. Throughout the years, we have witnessed international agreements on nuclear arms control that have come into force. Nevertheless, we still lack a comprehensive treaty that could prevent catastrophic impacts caused by nuclear testing. Putting a halt to nuclear testing is one of the most intense battles in arms control history. Thus, it is vital that we must start incorporating science and technology elements into our discussions. This study aim to analyzes science and technology elements in the Southeast Asian Nuclear-Weapon-Free Zone Treaty or the Bangkok Treaty. The analysis will include evaluating radionuclides released into the environment due to the nuclear explosion and nuclear fallout effect from a biological and environmental point of view and whether or not the Bangkok Treaty had considered the health and ecological

impacts of nuclear weapon detonation. Involvement of science in the policy-making process would ensure that the policy remains intact with the rapid developments of science and technology, and subsequently could continue to enhance operational capability. The results of this study, including lessons learned and best practices in the Bangkok Treaty, are expected to influence decision-makers in determining policies regarding nuclear testing.
Promotional text: Our study aims to open a dialogue between scientific groups and policymakers. We have broadened our knowledge of nuclear weapons bans by collaborating with various parties to conduct this research. At the same time, we are leaving a trail of awareness on our way.

T5.2 Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals

Highlights

O5.2-674 emphasized the value of open data from globally distributed geophysical instrumentation networks. The IMS has produced decades of valuable global geophysical observations in support of the CTBT explosion monitoring mission and can provide data for regions where no other data are available. The presentation described the work of the Incorporated Research Institutions for Seismology (IRIS) (USA) with global and regional networks such as the Global Seismographic Network and the EarthScope Transportable Array, which has enabled a wide range of transformative, cross-disciplinary research that has far exceeded original expectations.

These networks were designed to facilitate studies of earth structure and earthquake processes. The use of these data has been much broader, including studies of slow earthquakes, landslides, the earth's "hum", glacial earthquakes, sea state, climate change, induced seismicity and wildfires. These broad discoveries have been enabled because data sets are completely open and unrestricted, and the data and metadata are easily discoverable and well documented.

Earthquakes, Tsunamis and Volcanic Eruptions

P5.2-534 discussed the possible use of infrasound signals to map acoustic intensity, which is proportional to the shaking intensity of earthquakes. This was demonstrated with infrasound data from the 2010 Haiti earthquake detected in Bermuda, 1738 km away. Wavefront parameters retrieved in a beamforming process were back-projected to map the measured acoustic intensity to the source region. The polarity in the epicentral region was resolved. It was suggested that infrasound based ShakeMaps could be a potentially unique operational IDC product alongside conventional ShakeMaps for earthquake disaster mitigation in sparsely monitored regions.

O5.2-539 described a project by Earling (United Kingdom) to develop a means for earthquake early warning. It relies mostly on the accelerometers of smartphones, but CTBTO instruments can be useful for coverage in uninhabited regions where there are no smartphones or other instruments to record seismic patterns. Among the successes of the project was a 2020 alert to the Icelandic Meteorological Office a few days before the largest earthquake in Iceland since 2008.

P5.2-025 reported on the 2018 tsunami that hit the coasts of the Indonesian Island of Central Sulawesi. The tsunami accompanied an earthquake of Mw 7.5. The quake was spawned by a strike-slip fault (Palu-Koro fault), which is unusual because strike-slip faults displace land horizontally, not vertically. This suggests that the geological, geographical and tectonic details are important for understanding the causes and mechanisms of earthquakes and tsunamis in the region.

O5.2-318 presented a study of the 2015 earthquake swarm of the Fentale volcano in Ethiopia. The presence of volcano tectonic and long period events showed that the activity was induced by magmatic intrusion. This intrusion seemed to commence at depth and migrate to the south-west as it shallowed, to the centre of the activity. The study is important, as volcanic activity in this range could block Ethiopia's access road to the coast.

P5.2-471 considered the seismic moment tensor based on waveform inversion to investigate the sources of tectonic earthquakes and an alleged induced earthquake in the East Baltic region. An induced ML 4.4 "red light" earthquake on the North American platform was also used as a test sample. The advantage of the method is the ability to assess the seismic moment tensor for single stations. An estimate of the duration of the seismic process in the source can be a potential diagnostic feature.

P5.2-395 presented IMS signals from the eruption of the Taal volcano in the Philippines on 1 December 2020. The eruption was very well recorded by the monitoring system, as the three component auxiliary seismic station AS80 is situated only 11.8 km away from the volcano. Two REB infrasound events related to the most powerful eruptive activities were also recorded by the IMS infrasound network. Such close seismoacoustic activities are not often observed in the IMS network.

Arctic Monitoring

Infrasound signals from the IMS station IS18, located in north-west Greenland, bear the clear signature of melting glaciers, as described in O5.2-532. Different mechanisms, such as run-off and calving, generate infrasound. Sea and land terminating glaciers leave a distinctly different infrasonic signature. Sounds of the land terminating Qaanaaq glacier showed a substantial increase in activity in the summers of 2019 and 2020.

P5.2-016 presented characteristic features of infrasound waves observed in the Antarctic by an infrasound array installed at Terra Nova Bay, West Antarctica, in December 2015 by the Korea Arctic and Antarctic Research Program (KAARP). Variations of the oceanic background ("microbaroms") power spectral density are affected by evolution of the sea ice surrounding the Terra Nova Bay. More than two years of data demonstrate the variations in frequency content and amplitude.

P5.2-017 investigated the characteristics of seismic tremors in April 2015 at Syowa Station, Lützow-Holm Bay in East Antarctica. A large volume of sea ice was discharged, along with large icebergs that passed through the northern edge of the bay. Throughout the month, a total number of 49 tremor events were identified. Moderate Resolution Imaging Spectroadiometer (MODIS) satellite images were utilized for comparison with the tremor events. The most plausible candidate for the strong amplitude tremors is the collision between the bottom of drifting icebergs and the top of seabed sediments/crystalline rocks.

Regional Monitoring

P5.2-129 presented a brief overview of experience in risk and disaster assessment techniques in Niger and the prospects in terms of capacity building in this area. Especially when resources are scarce, it is important to optimize the actions and coordinate between the State, communities and other partners. P5.2-175 reported from Madagascar on more than 12 months of non-stop data from IMS stations HA4 (France), HA8 (United Kingdom) and HA1 (Australia) in an effort to define sources of hydroacoustic signals in the Indian Ocean. Signals that may be associated with tectonic events and ice breaking may have been observed. Seismic monitoring and observation is a vital function of the Seismological Observatory Section of the Solomon Islands, as described in P5.2-502. Auxiliary seismic station AS98 (Solomon Islands) was certified in 2005, and steps are now being taken to establish an NDC.

The observatory had recently integrated seismic and tsunami early warning monitoring. P5.2-451 presented data analysis of earthquakes around the Sabah region in Malaysia over a 19 year period, from 2002 to 2020. The results represent the preliminary findings of seismic hazard assessment in Sabah using IMS data.

P5.2-035 presented a new methodology of using parameters such as slope angle, land cover/land use, rainfall intensity and maximum wind speed to produce a wind hazard map. The methodology was applied to Bogor City in Java, Indonesia, where wind hazards are especially high during the rainy season, with 73 per cent of previous accidents related to wind hazards happening in that period.

P5.2-177 described the application of data from the monitoring network in Kazakhstan for the safety of nuclear facilities. Kazakhstan has research nuclear reactors, a low enriched uranium bank, tailing facilities, the Tokamak fusion reactor and the infrastructure of the Semipalatinsk Test Site. A nuclear power plant is planned to be constructed in the future. The seismic hazard in many parts of the country was poorly investigated and, as a result, underestimated. The contemporary data were analysed and generalized, and earthquake catalogues were created in order to estimate seismic hazards.

Lack of in-depth seismic hazard studies for West Africa has negatively impacted planning and disaster risk management. P5.2-033 aimed to address these challenges using modern techniques for seismic hazard studies. An earthquake catalogue was updated from various data sources including the IMS. Different ground motion models were applied to produce hazard maps using logic tree formalism with equal weights. Earthquake recurrence parameters were computed for the entire region. The study concludes that West Africa is characterized by a stable continental crust. The highest hazard levels were observed in parts of Ghana, Guinea and the Cameroon Volcanic Line region.

P5.2-045 discussed the impacts of multiple stressors on the ocean and the associated risks of abrupt shifts, rising sea levels and glacial melting, vis-à-vis climate variability. The study used high resolution satellite images to study the correlation of ocean–atmosphere–cryosphere interactions with climate variability to develop Arctic Ocean climate predicting models.

O5.2 Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals Abstracts of Oral Presentations

O5.2-318 – The 2015 Earthquake Swarm of Fentale Volcano: Multi-Hazard Threat for Ethiopia's Access to the Coast

Authors: Atalay Ayele[1]; Richard Luckett[2]; Brian Baptie[2]; Kathy Whaler[3]
[1]*Institute of Geophysics, Space Science and Astronomy of Addis Ababa University (IGSSA), Ethiopia*
[2]*British Geological Survey (BGS), United Kingdom*
[3]*University of Edinburgh, United Kingdom*
Corresponding Author: atalay.ayele@aau.edu.et

The Fentale-Dofen magmatic segment was shown to be more active than other volcanic centers in the northern Mid Ethiopian Rift by a temporary seismic experiment, conducted between 2001 and 2003 (Keir et. al., 2006). However, the activity observed during the EAGLE experiment is not swarm like but randomly scattered in time. In this study, we characterize rarely observed seismicity in the Fentale volcano neighborhood that occurred in March and April 2015 using reasonably good quality seismic data. Over 1,350 earthquakes are located and the activity is clustered around "Tinish" Fentale, northeast of

Fentale proper with a maximum magnitude of 3.5 ML. There are volcano-tectonic and long-period events, showing that the activity is induced by magmatic intrusion. This intrusion seems to commence at depth and migrate southwestward as it shallows, to the centre of the activity. This may imply that the magma feeding system of the Fentale-Volcanic Complex is either attributed to different sources or may all be influenced by the magma rich Afar Depression. This phenomenon is another geohazard threat, in addition to the lake level rise of Beseka, to Ethiopia's access to the active commercial route. This is a wakeup call to take precautionary measures to the concerned stakeholders.

Promotional text: The Fentale-Dofen magmatic segment is one of the active volcanic canters in Ethiopia that needs monitoring. Characterizing these volcanic sources can be used for Ground Truth events for improving crustal structure and also mitigating potential hazard for fast growing population.

O5.2-532 – The Sound of Melting Glaciers in Greenland in a Changing Climate

Authors: Läslo Evers[1]; Pieter Smets[2]; Jelle Assink[1]; Shahar Shani-Kadmiel[1]; K. Kondo[3]; S. Sugiyama[3]

[1]*Royal Netherlands Meteorological Institute (KNMI), De Bilt, the Netherlands*

[2]*Delft University of Technology, Delft, the Netherlands*

[3]*Hokkaido University, Sapporo, Hokkaido, Japan*

Corresponding Author: laslo.evers@knmi.nl

The infrasound component of the IMS is not only capable of detecting nuclear-test explosions, a wide variety of natural and anthropogenic sources are continuously measured by the network. A rich infrasonic wavefield is recorded by station I18DK, located in Northwest Greenland. I18DK is located in an unique environment far above the polar circle. Operations started in 2004, enabling long-term monitoring of its surroundings and building a statistically reliable soundscape. The infrasonic recordings reveal lots of infrasonic activity during summer, while the surroundings are infrasonically quiet in winter. The sounds are associated to glaciers around I18DK, active during the melting season. Different mechanisms like run-off and calving generate infrasound. It is found that sea and land-terminating glaciers leave a distinctly different infrasonic signature. The simultaneous observation of sounds from different glaciers over a long time period paves the way for studying the melting behavior in the Arctic cryosphere under a changing climate. Between the years a large variability is found in infrasonic activity of the glaciers. Such activity is quantified in terms glacier dynamics by comparing it to both modeled and locally measured run-off. Sounds of the land terminating Qaanaaq glacier show an increase in activity over the years.

Promotional text: Listening to inaudible sounds, infrasound, of Arctic glaciers under a changing climate.

O5.2-539 – CTBTO to Manage Earthquake Short-Term Risks

Author: Farzad Azima[1]

[1]*Earling Ltd, London, United Kingdom*

Corresponding Author: fximax@gmail.com

MEMS instruments are more commonly known as inexpensive instruments to create seismic monitoring systems. As a result, independent efforts would have access to the required data stream to start analysis and applying new-generation models to continuously detecting patterns that increased creativity amid managing risks of major earthquakes. In project Earling, such data helps to distinguish high-risk seismic patterns from low risk and normal patterns. As an example, Earling issued an alert to the Icelandic Meteorological Office a few days before Iceland's largest earthquake since 2008. MEMS instruments require setup, power supply, stable connectivity, maintenance, which also are some of their constrain alongside accuracy. Utilizing accelerometers of smartphones can overcome the limitation as a mobile app would do whatever is needed to turn a smartphone into one of the nodes of a seismic network, but most of the patterns can appear in uninhabited regions with no smartphone or other instruments to record the seismic patterns. Here, the CTBTO instruments can be very useful to draw a clear viewpoint of the current risk situation in its undercover regions to detect high-risk seismic time-window when the probability of an unusual event is remarkably increased, which accurate enough especially for transferring financial risks.

Promotional text: AI, CTBO instruments and new generation of disaster modeling now can be used together to detect high-risk time-window when probability of an unusual seismic activity is remarkably increased in a specified region. CTBTO data are very useful to manage or transfer the related risks.

O5.2-674 – The Value of Open Data from Globally Distributed Geophysical Instrumentation Networks

Authors: Robert Woodward[1]; Katrin Hafner[1]
[1]*Incorporated Research Institutions for Seismology (IRIS), Washington, USA*
Corresponding Author: woodward@iris.edu

High-quality open data from global and regional networks such as the Global Seismographic Network and the EarthScope Transportable Array have enabled a wide range of transformative, cross-disciplinary research that has far exceeded original expectations. The networks consist of well operated and distributed stations with long-term recording histories, and were designed to facilitate studies of Earth structure and earthquake processes. However, the use of these data has been much broader, including studies of slow earthquakes, landslides, the Earth's "hum", glacial earthquakes, sea-state, climate change, induced seismicity, and wildfires. These broad discoveries have been enabled because datasets are completely open and unrestricted, and the data and metadata are easily discoverable and well documented. Similarly, the International Monitoring System (IMS) has produced decades of valuable global geophysical observations in support of the CTBT explosion monitoring mission. The IMS, with its global distribution and high-quality can provide data for regions where no other data are available. Collectively, these various networks have contributed to capacity building, by providing data to scientists around the world, providing designs and standards for networks and stations worldwide, and engaging the public's interest in science.

Promotional text: Decade long, open, high quality data from Globally Distributed Geophysical Instrumentation Networks like the IMS can contribute to capacity building to scientists around the world, and provide data for broad discoveries far beyond the original CTBT explosion monitoring mission.

P5.2 Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals Abstracts of Poster Presentations

P5.2-016 – Characteristic Multi-Sphere Interaction in the Coastal and Marine Environment Inferred from Infrasound Observation at Terra Nova Bay, Antarctica

Authors: Masaki Kanao[1]; Takahiko Murayama[2]
[1]*National Institute of Polar Research, Tokyo, Japan*
[2]*Japan Weather Association, Tokyo, Japan*
Corresponding Author: kanao@nipr.ac.jp

Characteristic features of infrasound waves observed in the Antarctic reveal physical interaction involving surface environments around the continent and Southern Ocean. An infrasound array (100 m spacing) by using three sensors (Chaparral Physics Model 25, with a detectable frequency range of 0.1-200 Hz), together with a broadband barometer (Digiquartz Nano-Resolution Model 6000-16B Barometer, with a detectable frequency range of 0-22 Hz) were installed at Jang Bogo Staion, Terra Nova Bay, West Antarctica in

December 2015 by the Korea Arctic and Antarctic Research Program (KAARP). The initial data recorded by the broadband barometer include several signals originated surrounding surface environment, in addition to the local wind noises such as katabatic signals. Clear signals from background oceanic origin (the “microbaroms”) are continuously recorded at the austral summer on mid-December with predominant frequency around 5 s. Variations of their frequency context and strength appeared in Power Spectral Density are affected by evolution of the sea-ice surrounding the Terra Nova Bay. In this presentation, more than two years data is demonstrated by its variations in frequency content and amplitude with time.

P5.2-017 – Seismic Harmonic Tremors and Their Origins from Cryosphere Dynamics in the Lützow-Holm Bay, East Antarctica

Author: Masaki Kanao[1]
Co-author: Yoshihiro Hiramatsu[2]
[1]*National Institute of Polar Research, Tokyo, Japan*
[2]*Kanazawa University, Kanazawa, Japan*
Corresponding Author: kanao@nipr.ac.jp

Characteristics of seismic tremors in April 2015 were investigated at Syowa Station, in the Lützow-Holm Bay (LHB), East Antarctica. To examine the relationship between surface environment in a particular cryosphere variation, MODIS satellite images were utilized for comparison with the tremor events. Since a large volume of sea ice was discharged in April 2015, along with large icebergs passed through the northern edge of the fast sea ice of LHB, it was supposed to detect seismic tremors involving cryosphere dynamics in the region. Throughout the month, a total number of 49 tremor events were identified (Kanao et al., 2017). The majority of the events had a duration of over 15 minutes, which were divided into both tremors and ice shocks. Cryospheric sources recorded by seismic tremors were classified by their origins. In particular, strong amplitude tremors with harmonic overtones (Tanaka et al., 2019) were assumed to have occurred independently from meteorological condition. The most plausible candidate of the origins could be collisions between the bottom of drifting icebergs with the top of seabed sediments/crystalline rocks in places where the northern edges of continental shelf of LHB. Here the depths of the ocean floor can be less than 300 m from mean the sea level.

P5.2-025 – Trending Discussion on Indonesian Tsunami of 28 September 2018

Authors: Daya Shanker[1]; Nazeel Sabah[1]
[1]*Indian Institute of Technology, Roorkee, Uttarakhand, India*
Corresponding Author: d.shanker@eq.iitr.ac.in

This report presents on the recent tsunami that hit coasts of the Indonesian Island of Central Sulawesi. Indonesia, due to its location has experienced numerous tsunamis in recent times. The 2004 Indian Ocean tsunami is one of the most devastating among them. The latest one on 28th September 2018, at 18:02:44 a strong tsunami accompanied an earthquake of Mw 7.5 and left the state of Central Sulawesi worst affected. The tsunami was quite unprecedented as the quake was spawned by a strike-slip fault (Palu-Koro fault); usually, strike-slip faults displace land horizontally and not vertically and hence do not lead to a tsunami. This suggests that the geological, geographical and tectonic details of the island country are responsible in understanding the causes and mechanisms of earthquakes and tsunamis in the region. Foreshocks (Mw 6.1) and aftershocks (more than 150 in number) activities have also been analyzed. Satellite images of the region shot before and after the event highlight the devastation caused. The details of casualties and other associated damages have been collected from various sources. Various tsunami catalogues from 1500 to date estimates are assembled by causes, maximum magnitudes and water heights observed during the tsunamis as well as total fatalities.
Promotional text: The most disastrous hazards accompanying the earthquake is tsunami. It has often caused widespread

devastations leading to serious human, environmental and economic losses. I strongly believe these devastation and losses can be reduced by building resilience.

P5.2-033 – Seismicity and Seismic Hazard Assessment in West Africa

Author: Umar Afegbua Kadiri[1]
Co-author: Andrzej Kijko[2]
[1]*Centre for Geodesy and Geodynamics, Ministry of Science and Technology, Abuja, Nigeria*
[2]*University of Pretoria, South Africa*
Corresponding Author: umakad@yahoo.com

Lack of in-depth seismic hazard studies (SHS) for West Africa (WA) has negatively impacted planning and disaster risk management. Using modern techniques for SHS, this study aims to address such challenges. WA's earthquake catalogue was updated from various data sources including CTBTO. The seismotectonic setting of WA is assumed to be either, a stable continental crust or a shallow crustal seismicity. Therefore, we investigated both scenarios and compared results. For each, three different ground-motion models (GMMs) were applied and combined to produce each hazard map using logic tree formalism with equal weights. Earthquake recurrence parameters were computed for the entire WA region and five created seismic source zones within WA. The computed b-value, activity rates λ, regional maximum possible magnitudes mmax for the five zones and those for the entire region ranged from 0.84 to 1.0, 0.3–2.1, 5.2–7.0; and 0.77, 4.1, 7.2, respectively. The b-value of 0.77 falls within the generally accepted range for tectonic seismicity. The confirmation from our study that WA is actually characterised by stable continental crust is a monumental contribution. The highest hazard levels were observed in parts of Ghana, Guinea, and the Cameroon Volcanic Line region, ranging between 0.02 g and 0.03 g.

Promotional text: CTBT promotes civil and scientific applications of its techniques and data. Our study engendered revolution in West Africa by contributing in supporting exchange of knowledge, data and promotion of healthy collaboration with larger scientific community in line with CTBT's goals.

P5.2-035 – Climate Adaptation – Developing a Geospatial Technique for Quantifying Wind Hazards Using a Case Study in Bogor City, West Java, Indonesia

Author: Ahmad Agus Widodo[1]
Co-authors: Theuns Henning[2]; Sesa Wiguna[3]
[1]*Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), Jakarta, Indonesia*
[2]*University of Auckland, New Zealand*
[3]*National Disaster Management Authority of Republic of Indonesia (BNPB), Jakarta, Indonesia*
Corresponding Author: awid157@aucklanduni.ac.nz

Increasing windstorm occurrences significantly affect human lives, especially communities living in densely populated areas. However, windstorms commonly occur in a short period, with unexpected timing and at random places. Therefore, wind hazard maps must be developed to build resilience actions within communities. Bogor City area is used as a sample study and this research utilized GIS in developing wind hazard map. Further, this research develops a new methodology using parameters (slope-angle, land-cover/land-use, rainfall-intensity, and maximum wind-speed) to produce wind hazard map accurately that could be used to develop preventative action. As a result, it is evident that potential wind hazards are a high hazard category during the rainy season with around 73% of previous accidents happened at this category. It can be concluded that the generated maps can thus be used to describe the wind hazard of Bogor City region. According to the sample study, it should be noted that a developed map could describe the effectiveness of the methodology related to input parameters, pre-and -processing data, and producing a map. In general, the application of four critical parameters demonstrates that a developed methodology can be a new

paradigm in GIS modelling for wind hazard mapping.
Promotional text: This research was conducted as part of in Partial Fulfilment of the Requirement for the Master of Engineering in Disaster Management and should be published in international conference and journal.

P5.2-045 – High Resolution Satellite Study of Multiple Stressors in Arctic Marine Systems and Correlation of Ocean–Atmosphere–Cryosphere Interactions with Climate Variability to Develop Arctic Ocean Climate Predicting Models

Author: Virendra Goswami[1]
[1]*Environment and Peace Foundation, Noida, Uttar Pradesh, India*
Corresponding Author: vk_goswami1@rediffmail.com

The impacts of multiple stressors on the ocean and the associated risks of abrupt state shifts can be explored through ocean system interactions, risks, instabilities, synergies and Arctic Ocean climate predicting models. The draining of pools underneath the glacier and glacier retreat is attributed to increased carbon dioxide and green house gases. Hence, efforts are made on the co-evolution of climate and marine life in the Arctic Sea through the correlation of ocean-atmosphere-cryosphere interactions with climate variability i.e. to evaluate the correlation between the impacts of multiple stressors on the ocean and the associated risks of abrupt state shift, rising of sea levels, melting of the glaciers, vis-à-vis climate variability. The kinematic features of the mesoscale convective systems over the Arctic Ocean regions would be correlated with ocean-atmosphere-cryosphere variability on time and space scales and at local, regional and global levels through the extracted sea surface temperature (SSTs) over the grid box, attributing the regional change to natural and anthropogenic radiative forcing agents and bringing out a few optimum values of these to develop ocean systems interactions, risks, instabilities, and synergies and Arctic Ocean climate predicting models by using high resolution satellite imageries, data access, assimilation, HPC and cloud computing for real-time analysis.
Promotional text: Let us put efforts into the Co-evolution of climate and marine life in the Arctic-Sea through the Correlation of Ocean-atmosphere-cryosphere interactions with Climate Variability and save mother Earth from Environmental Pollution for the present and future generations.

P5.2-129 – Integrated Management of Natural Disasters and Resilience to Climate Change

Author: Issa Habou[1]
Co-author: Malam Maman Nafiou[2]
[1]*Protection Civile Niger, Niamey, Niger*
[2]*Université Abdou Moumouni (UAM), Niamey, Niger*
Corresponding Author: habouniger@gmail.com

Natural disasters are a serious disruption to the functioning of a community involving significant damage and loss of human life that the community cannot overcome with its own resources. The effects are often cumulative and felt over time and space. Thus, it is imperative to put in place a good prevention and risk management system that makes it possible to optimize actions, especially when resources are limited. This optimization necessarily requires a combination of the efforts and resources of the actors involved in the system. That is to say through close collaboration and coordination between the state, communities and partners. Aware of this need, Niger has created structures and put in place tools for early warning, assessment and emergency response. This paper gives a brief overview of Niger's experience in risk and disaster assessment techniques and the prospects in terms of capacity building in this area.
Promotional text: Natural hazards and their impacts on populations can vary over time and space. They can arise suddenly or evolve slowly but in either case they can be devastating for a community, country or region. The awareness by stakeholders of the impacts of dangerous phenomena is crucial.

P5.2-175 – CTBTO IMS Contribution to SDG 14: Life Below Water "Extended"

Author: Andriamendrikaja Jaona Andriamampandry[1]
Co-authors: Ilya Kursenko Vadimovich[2]; Ramarolahy Rina Andrianasolo[1]
[1]*Institute and Observatory of Geophysics of Antananarivo (IOGA), Madagascar*
[2]*CTBTO Youth Group*
Corresponding Author: jaopandry@gmail.com

During SnT19 we presented our work on defining the sources of hydroacoustic signals in the Indian ocean and looked at how the IMS can contribute to SDG 14. During the analysis we only managed to process three months of data from IMS HA04, HA08 and HA01. This time, we processed more than 12 months of non-stop data from those same stations. Data processing was performed using PMCC method with standard parameters for hydroacoustic signal detections. For each station we separated the detections into two main categories. The first category is the detections which remains present during the entire processing period. The second category is detections that requires further investigations, such as volcanos, land slide, breaking ice, cyclones and life below water. Constant detection was observed at stations H01W, H08S, H04N, respectively, between azimuth 140 and 250; azimuth 27 to 35 and 150 to 200; azimuth 0 to 100. We observed that those signals may come from tectonic events and ice breaking. For life below water it is still hard to say if we have detected any but this is included in NDC Madagascar's perspective.

Promotional text: This work is the fruit of researches and recommendations following the SnT2019. We brought updates and new approach especially for detection association.

P5.2-177 – Application of Kazakhstan Monitoring Network Data for the Safety of Nuclear Facilities

Authors: Irina Aristova[1]; Inna Sokolova[1]; Alexander Velikanov[1]; Alexander Sokolov[1]
[1]*Institute of Geophysical Research, Almaty, Kazakhstan*
Corresponding Author: i.aristova@kndc.kz

Since 1994, the Kazakh NNC RK has operated the contemporary monitoring system that includes seismic and infrasound stations. Five stations are included in the IMS: PS23, AS57, AS58, AS59, IS31. The main goal of the NNC RK network is monitoring of nuclear explosions in support of the CTBT. The data of NNC RK network are actively used in civil tasks, for example, to estimate the seismic hazard of places where the nuclear critical facilities are located. Kazakhstan possesses the research nuclear reactors, LEU bank, tailing facilities, Tokamak and the infrastructure of the Semipalatinsk Test Site. A nuclear power plant is planned to be constructed in the future. All these facilities are located in tectonically different regions of Kazakhstan. The seismic hazard of many Kazakh regions was poorly investigated and, as a result, underestimated. The contemporary data of NNC RK network and archive materials were analyzed and generalized, the earthquake catalogues were created for the regions where nuclear facilities of RK are located. The tectonic structure was studied, the database of strong motions was created, and the seismic hazard of the regions was estimated. The necessity to create the early warning system for earthquakes at the regions of the research nuclear reactors location is shown.

Promotional text: The NNC RK operates the contemporary monitoring system since 1994, 5 stations are included into the IMS: PS23, AS57, AS58, AS59, IS31. Data of the NNC RK network are used in civil tasks, to estimate the seismic hazard of places where the nuclear critical facilities are located.

P5.2-340 – Change Mitigation and Nuclear Weapon Testing/Explosion Reduction: Steps Towards Achieving Sustainable Development Goals

Author: Zile Huma[1]
[1]*Ministry of Human Rights, Pakistan*
Corresponding Author: zilehuma_1@hotmail.com

The fast-pace developments in scientific innovations introduced many new challenges for man-kind. The 21st century is facing many non-traditional security threats like climate change, pandemics, refugees' crises, resource scarcity etc. Both security and non-traditional security threats pose hinderance in the process of sustainable development and disaster risk mitigation efforts. On one hand climate disasters are putting human lives into danger by creating issues like health problems, financial crises, food insecurity and human rights issues. Similarly, nuclear weapon testing and explosions are also cause of many socio-economic and environmental disasters for mankind. Huge budgets are being spent for development of weapon of mass destruction which can be utilized to achieve various sustainable development goals. One important problem to combat these issues is lack of responsibility on part of various nations. We need to develop mass awareness on issues like climate change and nuclear testing and explosion at grass root level through development of curriculum and media engagement. We need to understand the link of many socio-economic problems with climate change and nuclear weapons development. In order to have an effective disaster risk management system we need to develop and implement policies which can mitigate climate change and prohibit nuclear weapon testing/explosion.

Promotional text: Climate Change/environmental and nuclear testing have common, political and socio-economic negative impacts for mankind. Both problems require collective efforts at all levels to develop effective policies and create mass awareness to mitigate disasters impacts.

P5.2-395 – The 2020 Taal Volcano (Philippines) Eruption as Recorded by the International Monitoring System

Author: Aaron Joseph Gutierrez Jimenez[1]
Co-authors: Baby Jane Punongbayan[1]; Ronan Le Bras[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author:
aaron.joseph.gutierrez.jimenez@ctbto.org

On 12 January 2020, Taal Volcano (Philippines) had a strong phreatomagmatic eruption producing a 10-15 km ash column and ashfall reaching as far as Quezon City (~80 km). Taal is one of the most dangerous volcanoes known, with 34 eruptions since 1572, and eruptions being phreatic, phreatomagmatic, strombolian or plinian (e.g. 1954). Increased volcanic activity has been observed for a year but rapid intensification on 12 January prompted PHIVOLCS, the Philippine volcano warning agency, to raise the alert from level 1 to level 4 (hazardous eruption imminent), requiring immediate evacuation of thousands of people. The crisis lasted for 2 weeks with fissuring, ground deformation and high seismicity attributed to magma and gas intrusions. The decline in seismicity helped in lowering the alert level on 26 Jan. This eruption history was very well recorded by the CTBTO IMS as the 3-component auxiliary station AS80 (TGY) was situated only 11.8 km away from the volcano. In addition, two REB infrasound events related to the most powerful eruptive activities were also recorded by the IMS infrasound network. Such close seismo-acoustic activities are not often observed on the IMS network. This poster will present the seismicity and infrasound events as seen by the IMS.

Promotional text: One of the areas of interest of the CTBTO is the disaster early warning, The CTBTO's Member States and international and national institutions responsible, receive this information to perform on time an effective exercise of evacuation.

P5.2-451 – Analysis on Earthquake Databases of the Sabah Region and Its Application for Seismic Hazard Assessment Using the IMS Data of the CTBTO

Author: Muhammed Zulfakar Zolkaffly[1]
Co-author: Faisal Izwan Abdul Rashid[1]
[1]*Malaysia Nuclear Agency, Selangor, Malaysia*
Corresponding Author: zulfakar@nm.gov.my

Sabah is the most seismically active state in Malaysia where it has recorded higher number of moderate seismological activities for the past decades. The seismicity record of Sabah shows the presence of two distinctive seismic zones, which are Ranau in Kota Kinabalu and Lahad Datu in the southeast of the region. The IMS network setup by the CTBTO has successfully detected seismic events occurred in the region for the past decades. In this study, we present the results of data analysis of earthquake events occurred around Sabah region, distributed over 19 years' periods, from 2002 to 2020. The results represent the preliminary findings of seismic hazard assessment (SHA) in Sabah using the IMS data, where the results have enabled the quantification of seismic hazard in the region in terms of recurrence periods and probabilities of occurrence of earthquake at any given magnitude. This study demonstrates that other than for nuclear explosion monitoring, the IMS data can also be used for civil and scientific applications and can make significant contribution in seismological research. Consequently, the findings could be used to assess the impact of seismic events in Sabah as well as assisting relevant entities in development planning and disaster management.

Promotional text: The IMS monitoring capability of seismicity leads as well to the estimation of the seismic hazard posed by earthquakes in many different localities, on which one of the many potential civil applications of IMS data. In addition to many other proven studies that had been performed.

P5.2-471 – Use of the Seismic Moment Tensor to Recognize the Genesis of Seismic Events in the East Baltic Region

Authors: Dmytro Malytskyy[1]; Valerijs Nikulins[2]
[1]*National Academy of Science of Ukraine, Lviv, Ukraine*
[2]*Latvian Environment, Geology and Meteorology Center, Riga, Latvia*
Corresponding Author: valerijs.nikulins@lvgmc.lv

Energy facilities and natural resource development are potential sources of anthropogenic impact on tectonic stresses in the earth's crust. The consequence of this can be provoked seismicity, which can be divided into induced seismicity and trigger seismicity. Provoked seismicity can be dangerous for the above-mentioned objects. However, signs of difference between tectonic and provoked earthquakes continue to remain relevant. The seismic moment tensor (SMT) based on waveform inversion is considered as a potential feature. The object of research is the sources of tectonic earthquakes and the alleged induced earthquake 2015/06/12 in the East Baltic region, located on the East European platform. The region is characterized by low seismic activity, a large number of quarry blasts and the presence of environmentally hazardous energy facilities. An induced earthquake of 2015/06/13 ("Red-light") ML 4.4 on the North American platform is also used as a test sample. The complex of analyzed parameters is supplemented by other characteristics of the earthquake source (seismic moment, moment magnitude, stress drop, source radius). The advantage of the method is the ability to assess the SMT for single stations. An estimate of the duration of the seismic process in the source can be a potential diagnostic feature.

Promotional text: The main contribution of the presentation is to search for perspective signs to distinguish between tectonic earthquakes and provoked earthquakes (induced and triggered) at East-European craton. One of the promising parameters of the SMT may be the duration of the seismic process.

P5.2-502 – Seismic Monitoring and IMS Collaboration

Author: Belinda Waokahi[1]
[1]*Seismological Observatory Section, Ministry of Energy, Mines and Rural Electrification, Solomon Islands*
Corresponding Author: belinda.waokahi@gmail.com

Seismic monitoring and observation is a vital and main function of the Seismological Observatory Section of the Solomon Islands. The Solomon Islands are formed from part of a complex of Melanesian island arcs and are located on the South West Pacific Region NW of Papua New Guinea and SE of Vanuatu Islands. Due to tectonic settings of a complex plate of convergent zone, the seismicity of the Solomon Islands are relatively high. Thus Seismological Observatory Section is focusing on developing more on earthquake monitoring. Solomon Islands had signed the verification with CTBTO in 1996 and then collaborated through the Seismological Observatory Section which then certified its HNR Station in 2005 as an auxiliary seismic station AS098 to carry out seismic monitoring for nuclear explosion monitoring. From then, it had continued engagement with the observatory and carried out sending seismic data to IDC on request. It is currently working towards becoming a National Data Center. With its aims and obligations, the observatory had recently integrated a seismic and tsunami early warning monitoring and is working towards solving current challenges faced with the National Seismic Network.
Promotional text: The Seismological Observatory Section of the Solomon Islands had its main role and obligation to develop and maintain a national network of seismic stations to monitor seismic and volcanic activity and to fulfill national obligations with the Global Seismic Network and CTBTO.

P5.2-534 – The 2010 Haiti Earthquake Revisited: An Acoustic Intensity Map from Remote Atmospheric Infrasound Observations

Authors: Shahar Shani-Kadmiel[1]; Gil Averbuch[2]; Pieter Smets[3]; Jelle Assink[1]; Läslo Evers[1]
[1]*Royal Netherlands Meteorological Institute (KNMI), De Bilt, the Netherlands*
[2]*Southern Methodist University, McKinney, TX, USA*
[3]*Delft University of Technology, Delft, the Netherlands*
Corresponding Author: shahar.shani.kadmiel@knmi.nl

Following the January 12, 2010 Mw 7 Haiti earthquake, the shaking intensity near the epicenter was overestimated and the spatial extent of the potentially damaging shaking was underestimated. This was due to the lack of seismometers in the near-source region at the time of the earthquake. Besides seismic-waves, earthquakes generate infrasound, i.e., inaudible acoustic-waves in the atmosphere. Here we show that infrasound signals, detected at distant ground-based stations, can be used to map the acoustic intensity, which is proportional to the shaking intensity. This is demonstrated with infrasound from the 2010 Haiti earthquake detected in Bermuda, 1738 km away. Wavefront parameters retrieved in a beamforming process are backprojected to map the measured acoustic intensity to the source region. Furthermore, we resolve the polarity in the epicentral region. Infrasound measurements are conducted globally for the verification of the Comprehensive Nuclear-Test-Ban Treaty and although the network was designed to provide global coverage for nuclear explosions in the atmosphere, we show that there is also global coverage for the estimation of acoustic shaking intensity. In this study, we lay the groundwork that can potentially make infrasound-based ShakeMaps a unique operational IDC product alongside conventional ShakeMaps for earthquake disaster mitigation in sparsely monitored regions.
Promotional text: Remote infrasound detections can complement earthquake near-source seismic measurements.

This can potentially make infrasound-based ShakeMaps a unique operational IDC product alongside conventional ShakeMaps for earthquake disaster mitigation in sparsely monitored regions.

P5.2-555 – CTBTO's Contribution to Improving Education and Research Quality and Mitigating Climate Change

Author: Asad Ur Rehman[1]
[1]*National Defence University Islamabad, Pakistan*
Corresponding Author: assadurrehmankhan@gmail.com

The International Data Centre (IDC), which is present in Vienna, receives information from the International Monitoring System (IMS). The IMS has radionuclide, seismic, and hydroacoustic stations around the globe which gather data about air quality, land and oceans respectively. This regularly updated scientific data can be used by the "students of Environmental Science and Global Environmental Politics" for the research and assessment of environmental problems such as climate change. Most of today's research in these fields is based upon assumptions and theoretical scenarios which is inadequate to solve the environmental issues properly. The availability of the data provided by IDC to the students will equip them to perform better and precise research. This study illustrates how the availability of the scientific developments achieved by CTBTO to the students will improve the education and research quality in the member states and how the use of updated scientific data in research will help in finding proper solutions for environmental problems.
Promotional text: The study illustrates the usefulness of the CTBTO's scientific developments and data in improving education and research quality in the member states, and mitigating the climate change.

5.3 Capacity Building, Education, Communication and Public Awareness

Highlights

Outreach and Education, Communication and Public Awareness

O5.3-525 emphasized the role of diplomats in the OSI process. A crucial issue is how to prepare both scientists and diplomats to interact properly in the field using common motivation, language and training. To achieve this, diplomats must not only learn about OSI technologies but also participate in field exercises in order to confirm that the data arising from scientific work are reliable, trustworthy and can be used for decision making at the political level.

O5.3-103 and P5.3-463 described how the Moscow Engineering Physics Institute (Russian Federation) established the Science Diplomacy Club to build bridges in the field of science and technology. The club aims to encourage intergenerational dialogue between students and high profile experts in the field of non-proliferation, disarmament and the banning of nuclear tests and to raise awareness of current challenges. The oral presentation described the experience of incorporating the NPT Review Conference model as an extended role-play simulation. This multilateral negotiation exercise was an effective learning technique in science diplomacy education.

O5.3-696 presented new public opinion data on explosive nuclear tests. The data are based on nationally representative surveys conducted in Belgium, France, Germany, Italy, Japan, the Netherlands, Poland, Sweden, Turkey, the United Kingdom and the United States of America. The surveys demonstrate overwhelming public opposition to nuclear testing while also revealing (mis)perceptions about the effects of nuclear test explosions.

P5.3-319 discussed the extensive efforts of the PTS to advance public awareness of the Treaty and what non-governmental organizations (NGOs) have done to further this effort. Despite the establishment of the impressive GEM and CYG, more must be done to engage with civil society. Academics, NGOs and scientific groups can establish coalitions and participate in educational panels, workshops and speaking engagements at meetings and major international conferences.

P5.3-578 introduced the CTBTO Youth Academy of Sciences, an initiative for research and educational projects that involves CYG members in CTBT research. The participants will work in groups of four to five on topics such as verification issues, Article XIV, science diplomacy and IMS applications. Each group will have a scientific supervisor from GEM to bridge the younger and more experienced generations. The resulting papers are to be published in the Newsroom magazine, on the CTBTO web site and on other platforms to revitalize discussion around the CTBT.

P5.3-681 discussed the public outreach of the CTBTO. While citing the CYG as an example of successful outreach and education, the presentation highlighted the potential of museums and cultural, historical and scientific centres as pathways to connect with other educative platforms, promote the Treaty in non-nuclear civil society areas (i.e. climate) and provide a new avenue for possible collaboration and awareness. P5.3-655 described an open day at IMS stations PS19 and IS26 in the Bavarian Forest (Germany) following extensive refurbishment and recapitalization works. Approximately 600 people visited the relatively remote site, as well as a group of diplomats based in Vienna. P5.3-580 explored how the current landscape of arms control treaties, including the Treaty on the Non-Proliferation of Nuclear Weapons and the Treaty on the Prohibition of Nuclear Weapons, affect the CTBT. P5.3-617 emphasized the possible importance of NDCs in the ratification of the CTBT. P5.3-054 called for implementation of an optional university discipline related to engineering and non-proliferation for students specializing in research.

P5.3-682 and P5.3-685 described the CYG as a prime example of a communications model for track II diplomacy. With almost 1000 members from diverse backgrounds, it connects science and policy in an interdisciplinary way. Through nuclear disarmament and non-proliferation education, the group provides members opportunities to actively engage in track II diplomacy channels.

Regional Developments

P5.3-157 described joint seismic monitoring activities in Central Asia, an area that is tectonically very active. As a result, seismic monitoring is important and has both scientific and social significance. For many years, NORSAR (Norway), the Institute of Geophysical Research (Kazakhstan) and the Institute of Seismology (Kyrgyzstan) have cooperated in a joint scientific programme on technical verification of compliance with the CTBT, as well as research on improved seismic monitoring. Under this cooperation, seismic stations and the NDCs in Kyrgyzstan and Kazakhstan were upgraded, and Central Asian seismologists were trained at the training centre established at the NDC in Kazakhstan. In 2018, joint work began to compile a new seismic bulletin for Central Asia based on data from 51 stations and 5 arrays. Induced, anthropogenic and natural seismicity from different regions with mining activities in Kyrgyzstan and Kazakhstan as well as icequakes in the Tien Shan glaciers were analysed.

O5.3-072 discussed the utilization of NDC data in geoscience education in Bangladesh and highlighted the need for capacity building at the NDC to support the implementation of these activities. As part of research and development work at the NDC, the Bangladesh Atomic Energy Commission is collaborating with the geology departments of several universities. The use of RSTT to analyse subsurface geological information using auxiliary station AS7 in combination with the other seismic stations in the region was cited as an interesting example.

P5.3-222 presented a scientific promotion programme launched by the NDC in Chile. Its objective is to develop data processing capabilities and encourage the use of IMS data in scientific research. The programme promotes the civil benefits of the CTBT and identifies opportunities for agreements with scientific institutions. In addition to describing the steps taken to develop the programme, it also highlights the obstacles encountered, such as the COVID-19 pandemic.

P5.3-288 focused on improvements in data analysis since the installation of the NDC in Costa Rica in 2010. For example, real time inclusion of data from IMS seismic stations and OVSICORI local seismic stations is now automatically performed through the SeisComP3 acquisition system included in the NDC in a box software package. In addition, in recent years all data analysis programs such as Geotool, DTK-GPMCC, DIVA, WEB-GRAPE and SeisComP3 have been updated to be accessible to users at the NDC in Costa Rica.

P5.3-569 advocated for the establishment of an NDC in Brazil. Although Brazil does not yet have an NDC, its creation has recently been discussed. To contribute to these discussions, the book *The Brazilian Participation in the Verification of CTBT* was written to emphasize the importance of establishing an NDC in Brazil and the potential advantages, as well as the demonstrated importance of the CTBT in terms of the control of nuclear weapons and the establishment of a solid social scientific knowledge base through the application of IMS data.

P5.3-314 discussed geothermal prospecting in Kenya. Seismic hydraulic diffusivity was investigated to examine the implications of fluid circulation on seismic activity at a geothermal prospect. A dense seismic network is required, but in most cases only a few stations are available. Data from IMS seismic stations can be used to improve the quality of data and the accuracy of results.

P5.3-447 discussed how Nepal can benefit from the IMS network, especially in the monitoring of seismic activity and radionuclides. It also called for strengthening the link between the National Youth Council of Nepal and the CTBTO.

P5.3-136 discussed the efforts of the Tunisian NDC to ensure the smooth functioning of IMS stations PS42 and IS48, which have been in operation for 15 years (2006–2021). It described upgrading and calibration activities, national capacity building activities and the establishment of a method of work that prioritizes data analysis and contributes to civil and scientific applications.

Scientific Communication, Data Sharing and Analysis

O5.3-639 described the CTBTO link to the database of the International Seismological Centre (ISC) (United Kingdom). The link provides PTS and NDC users dedicated access to long term definitive global data sets maintained by ISC using specially designed graphical interfaces, database queries and non-IMS waveform requests. This service gives access to the ISC Bulletins on natural seismicity of the earth, mining induced events, and nuclear and chemical explosions; the ISC-EHB data set; the ground truth reference event list of the International Association of Seismology and Physics of the Earth's Interior and the ISC Event Bibliography. As an example of the use of the link, the ISC provided ground truth events to be used for training of States Signatories to the CTBT. It is also regularly used by NDCs and the PTS.

P5.3-530 gave examples of how to process and analyse IMS data obtained in real time through the newly developed SeedLink service available on the GCI, using the seismic analysis software package SEISAN. SEISAN is used in more than 30 countries, mainly at smaller seismic networks or by students or researchers, for processing data from permanent or temporary seismic networks and at a number of NDCs. Integration of sensor data and metadata and event parametric data from the CTBTO with locally collected data will enable NDCs to improve nuclear test monitoring.

P5.3-020 presented analysis by the CTBTO Library that used bibliometric and scientometric techniques to create network visualizations of scientific communication by the organization over the last 25 years (1996–2021). These visualizations are an innovative approach to characterizing the complexity and diversity of the connections between experts, subjects of common interest, institutions and countries. The software Mendeley (free) and VOSviewer (open source) were used, and metadata was crucial to this work.

O5.3-413 focused on analytical recognition and knowledge sharing. The author analysed the evolution of topics presented at CTBT: Science and Technology conferences from 2006 to 2021, capitalizing on scientific and technological applications, trends, innovations and worldwide collaborations. The goal of the work is to provide direction on the knowledge management approach for deep content analysis and to strengthen the role of knowledge organization systems as a tool for analysing and disseminating content.

O5.3 Capacity Building, Education, Communication and Public Awareness
Abstracts of Oral Presentations

O5.3-072 – Utilization of CTBT-NDC Data in Geoscience Education of Bangladesh

Authors: Mohammad Rajib[1]; Md. Golam Rasul[1]; Md. Hasinur Rahman[1]
[1]*Bangladesh Atomic Energy Commission, Dhaka, Bangladesh*
Corresponding Author: rajib.mohammad@gmail.com

Bangladesh, a Comprehensive Test Ban Treaty (CTBT) signatory country since 24 October, 1996, is the 54th state to ratify CTBT on 8 March, 2000. Auxiliary Seismic Station (AS007 BRDH) in Bangladesh, accredited as an internationally certified station, receives the seismic data from International Data Center (IDC) of CTBTO. The seismic station AS007 was established to monitor the activities of nuclear testing through seismic wave propagation in the region. Geoscientists of different academic and professional institutions have been analyzing seismic travel time data from various sources. Accordingly, the objective of the present report is to find out the potential application of regional seismic travel time (RSTT) data in the geoscience researches of Bangladesh. The RSTT data can be applied to analyze this subsurface geological information with the combination of other CTBT seismic stations of the region. Besides seismic data, the IDC has other products, such as radionuclide and noble gas distribution data around the world, hydro-acoustic data for tsunami warning system, etc. Therefore, there is ample scope of introducing IDC products to the geoscience education of Bangladesh. As part of R&D activities through the CTBT-NDC, BAEC is working on this aspect by collaborating with the geology departments of several universities.

Promotional text: The proposed study is aimed to introduce the IDC products for their potential application in geoscience education in Bangladesh as well as the necessity of the capacity build up of NDC to implement the activities related to the objectives.

O5.3-103 – Role-Play Simulations as Effective Participatory Learning Techniques in Science Diplomacy Education

Author: Elena Tsyvkunova[1]
[1]*National Research Nuclear University MEPhI, Moscow, Russian Federation*
Corresponding Author: eltsyvkunova@rambler.ru

MEPhI Science Diplomacy Club (SDC) aims to nurture a new generation of experts who are curious about cross-cutting issues at the interface of science and international relations, who are willing to bridge diplomatic challenges & technical solutions and who are eager to learn more about current challenges including nuclear test ban, non-proliferation and disarmament. The SDC members participate in a wealth of outreach and education activities comprising webinars with experts, presentation contests, summer seminars for pre-university students, Science Diplomacy School, career talks etc. Due to restrictions caused by the COVID-19 pandemic, we had to fully utilize evolving pedagogic methods including distance learning and videoconferencing with a view to holding SDC events in a remote format. We'll use the occasion of the SnT21 to share our experience of incorporating simulations and roleplays, which are deemed to be one of the most effective participatory learning techniques, into multidisciplinary educational programs. Moreover, we'd like to share our main learnings from The 2020 NPT Review Conference Model which not only highlighted the NPT-CTBT nexus but also showcased the distinct role of the CYG in increasing the visibility of the CTBT.
Promotional text: Virtual simulations provide unique opportunities for students to delve into nuclear test ban and non-proliferation as they are one of the most effective participatory learning techniques in science diplomacy education. They represent a bumpy ride but very rewarding and impactful!

O5.3-413 – Knowledge Management in the Context of Comprehensive Nuclear-Test-Ban Treaty (CTBT) Science and Technology

Author: Marija Sejmenova-Gichevska[1]
[1]*Former CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: sejmenova@gmail.com

In support to the Comprehensive Nuclear-Test-Ban Treaty, the worldwide scientific community – via the CTBT SnT Conferences - has the opportunity to build partnerships and encourage knowledge exchange, allowing the CTBTO to remain at the forefront of the relevant technology for test-ban verification. The SnT Conferences are organized biennially by the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO). This paper analyses the CTBT SnT topics presented at the Conferences from 2006-2021, capitalizing on scientific and technological applications, trends, innovations and worldwide collaborations. The goal of this work is to provide directions on the knowledge management approach for deep content analysis, strengthening the role of Knowledge Organisation Systems (KOS) as a mechanism and tool for analysing and disseminating content. This research reflects the necessity of creating a KOS-based tool for knowledge recognition and discovery that will encourage communication in a valuable way.
Promotional text: Analysing the topics from SnT Conferences 2006-2021, the paper reflects the necessity of creating a Knowledge Organisation System-KOS-based tool for deep content analysis that will encourage CTBT SnT knowledge communication and reuse on a valuable way.

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

O5.3-525 – Scientist and Diplomats On Site!

Author: Gustavo Gonzalez[1]
[1]*Ministerio de Relaciones Exteriores de Chile, Chile*
Corresponding Author: ggonzalezb@minrel.gob.cl

In the context of the nuclear non-proliferation regime, the On-Site Inspection of the CTBTO plays a major role for verification. OSI is when Scientists from different fields and diplomats get together with a common aim: "to identify signs from a nuclear explosion". Only a perfect match between science knowledge and diplomatic skills can assure full success for an OSI. The crucial issue is how to prepare both to be ready to go in to the field and interact properly using a common language and having the same training and motivation. For this to happen diplomats must correctly learn not only about the whole range of technologies involved in an OSI but to experiment in field exercises in order to confirm without any doubt that the data arising from scientific work are reliable, trustworthy and can be used for a proper decision at the political level.
Promotional text: Scientist and Diplomats for a successful OSI.

O5.3-639 – CTBTO Link to the ISC Database as a Tool for Capacity Building and Education

Authors: Dmitry Storchak[1]; Ryan Gallacher[1]; James Harris[1]
[1]*International Seismological Centre (ISC), United Kingdom*
Corresponding Author: dmitry@isc.ac.uk

The CTBTO Link to the database of the International Seismological Centre (ISC) is a service provided on behalf and by arrangement with IDC/CTBTO. The Link enables PTS and National Data Centres (NDC) with dedicated access to long-term definitive global datasets maintained by ISC using specially designed graphical interfaces, database queries and non-IMS waveform requests. This service gives access to the ISC Bulletins of natural seismicity of the Earth, mining induced events, nuclear and chemical explosions; the ISC-EHB dataset; the IASPEI Reference Event list (GT) and the ISC Event Bibliography. The searches are tailored to the needs of the monitoring community and divided into four categories: Area based spatio-temporal search (based on ISC Bulletin), REB based spatio-temporal search, GT event based search and the IMS station based search (historical reporting patterns of stations close to IMS sites). We recently made several additions, for example, a service reporting suspected time periods of inverted polarities at openly available seismic stations. The Link demonstrates one of the CTBTO efforts in capacity building for NDCs and education of new generation of seismologists working in monitoring research. The Link is regularly used by the NDCs and PTS and proved useful during recent CTBTO Exercises.
Promotional text: The CTBTO Link to ISC database supports the exchange of knowledge between CTBTO and broader scientific community, promotes the wider data used for test ban verification and contributes towards CTBTO capacity building and educational efforts.

O5.3-696 – Banning Nuclear Tests: The Role of Public Opinion Research

Authors: Stephen Herzog[1]; Benoît Pelopidas[2]; Jonathon Baron[3]; Fabrício M. Fialho[4]
[1]*Yale University, CT, USA*
[2]*Institut d'études politiques de Paris, France*
[3]*Independent Scholar*
[4]*Cardiff University, United Kingdom*
Corresponding Author: stephen.herzog@yale.edu

In recent years, there has been a rapid increase in social scientific studies using polling techniques to better understand nuclear issues. Scholars have shown public opinion in numerous countries on subjects such as nuclear proliferation, deterrence posture, and links between civilian and military nuclear technologies. These studies are important contributions for improving decision-maker accountability and more effectively shaping policy to represent public views.

We contribute to these discussions by presenting new public opinion data on nuclear explosive testing. The data come from nationally representative surveys we conducted in Belgium, France, Germany, Italy, Japan, the Netherlands, Poland, Sweden, Turkey, the United Kingdom, and the United States. The surveys demonstrate overwhelming public opposition to nuclear testing while also revealing (mis)perceptions about the effects of nuclear test explosions. Taken together, they provide useful information for policy, advocacy, and education aimed at promoting entry-into-force of the Comprehensive Nuclear-Test-Ban Treaty (CTBT).

Promotional text: This e-poster shows how public opinion polling can inform policy, advocacy, and education to improve understanding of nuclear test explosions and promote entry-into-force of the Comprehensive Nuclear-Test-Ban Treaty (CTBT).

P5.3 Capacity Building, Education, Communication and Public Awareness Abstracts of Poster Presentations

P5.3-020 – Analysis of CTBTO Scientific Communication Using Network Visualizations

Authors: Flor Elisa Trillo-Tinoco[1]; Gerard Rambolamanana[1]
[1]*CTBTO Preparatory Commission, Vienna, Austria*
Corresponding Author: flor.trillo.tinoco@ctbto.org

The CTBTO Library has created an extensive analysis of the CTBTO scientific communication. This was possible using bibliometric and scientometric techniques, through key network visualizations to represent its contribution to the global scientific community during the last 25 years of international collaboration. In the context of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification system, this analysis includes the content of more than 2,500 documents such as scientific articles, conference proceedings, reports, books, book chapters, expert reports, and dissertations (1996-2021) where experts in nuclear test detection from different backgrounds and types of institutions interact and contribute with innovative solutions to improve the verification regime. In this framework, the network visualizations offer an innovative approach to represent the complexity of this universe. With this technique, it has been possible to determine all the variety and diversity characterizing all the connections between experts, subjects of interest in common, institutions, and countries. This work was possible with the following software: a) Mendeley (free software), and b) VoSviewer (open software). The role of the Metadata was crucial, especially to standardize of author's names, keywords, institutions, and countries. These representations express how clusters are interconnected, their co-occurrence, and relatedness based on the frequency of publications.

Promotional text: CTBTO 25 years of Scientific Communication.

P5.3-054 – Converging Knowledge and Technology Role on University's Non-Proliferation Culture

Author: Artur Buzdugan[1]
Co-author: Aurelian Buzdugan[2]
[1]*Technical University of Moldova, Chrisinau, Moldova*
[2]*Moldova State University, Chrisinau, Moldova*
Corresponding Author: artur_buzdugan@yahoo.com

University, indispensable for research, is one of the pillars of the prosperity and security of future generations. The diversification of research impose new ethical rigor hanging in the dissemination of the results. Responsible management of research in universities requires active commitments from relevant institutions. The progress in free access to information on the internet shows an increase role of security in scientific and innovative databases, especially of unclassified information for various reasons for dual use materials and technologies. Research is most vulnerable to unethical use because it generates and provides knowledge, materials, methods and technologies that could be channeled into crime or terrorism.

However, scientific researchers and engineers play a key and responsible role in nonproliferation. Researchers are the most knowledgeable and best placed professionally to assess the nature and seriousness of the potential for misuse of knowledge, products or technologies. In this way, they should be the most responsible for evaluating and reporting on these findings within the research institution and to relevant national bodies. It is imperative to implement an optional discipline related to engineering and non-proliferation for students specializing in research. Such an alternative or optional course is currently under development at the mentioned technical university center.

Promotional text: Convergence of engineering education, Research and Non-proliferation, Research Ethics.

P5.3-136 – 15 Years Achievements as NDC-TN

Authors: Noureddine Triqui[1]; Atef Blel[1]

[1]*Centre National de la Cartographie et de la Teledetection (CNCT), Tunis, Tunisia*

Corresponding Author: triquinoureddine@gmail.com

From 2006, when Tunisian IMS station (PS42 and IS48) started sending data, the NDC-TN has made a concerted effort to effectively participate in the verification regime of the Treaty and to implement obtained knowledge and capacities at the national, regional and international levels. This poster will give you an idea on how the NDC-TN: ensures the smooth functioning of the stations and the maintenance at the first level as well as its participation in various exercises relating to the updating of the hardware and software of stations, such as IS48 and SSI upgrades, calibration, et cetera; places a large importance on the development of national capacity building and the establishment of a methodology of work; prioritizes data analysis (SHI and R) and contributes to the promotion of civil and scientific applications.

Promotional text: Tunisian NDC is making efforts to establish a methodology of work to implement capacity building methods and ensure the good functioning of the IMS stations in order to improve nuclear test monitoring and verification.

P5.3-157 – Joint Seismic Monitoring Activities in Central Asia

Authors: Natalya Mikhailova[1]; Anna Berezina[2]

Co-authors: Johannes Schweitzer[3]; Irina Aristova[1]; Kanatbek Abdrakhmatov[2]; Svein Mykkeltveit[3]; Inna Sokolova[1]; Elena Pershina[2]; Helene Ruud[3]

[1]*National Nuclear Center of the Republic of Kazakhstan, Kurchatov, Kazakhstan*

[2]*Institute of Seismology, National Academy of Science (IS NAS KR), Bishkek, Kyrgyzstan*

[3]*Norwegian Seismic Array (NORSAR), Kjeller, Norway*

Corresponding Author: mikhailova@kndc.kz

Central Asia is tectonically complicated with high seismic activity. Over the past 150 years four great earthquakes occurred with magnitudes exceeding 8. Seismic monitoring is one of the most important problems of the region, having both scientific and social significance. Since many years, NORSAR (Norway), the Institute of Geophysical Research (Kazakhstan), and the Institute of Seismology (Kyrgyzstan) are cooperating to solve this problem. A joint scientific program is focusing on capacity building in Central Asia, in relation to technical verification of compliance with the CTBT, as well as research on improved seismic monitoring. Under this cooperation, seismic stations and the National Data Centres (NDC) in Kyrgyzstan and Kazakhstan were upgraded and Central Asian seismologists were trained at the Training Centre, established at Kazakhstan's NDC. In 2018, joint work started on compiling a new seismic bulletin for Central Asia, based on data from 51 stations and 5 arrays. Observed magnitude and energy class discrepancies were studied with respect to systematic station and network effects. Aftershock sequences of 80 earthquakes with different magnitudes were analysed. The induced, anthropogenic and natural seismicity from different regions with mining activities in Kyrgyzstan and Kazakhstan as well as icequakes in the Tien Shan glaciers were analysed.

P5.3-222 – Scientific Promotion Programme for IMS Data in Chile

Author: Christopher Celis Huaiquilaf[1]
[1]*Chilean Nuclear Energy Commission (Comisión Chilena de Energía Nuclear), Santiago, Chile*
Corresponding Author: christopher.celis@cchen.cl

The National Data Center in Chile is established at the Chilean Nuclear Energy Commission. Its principal mandate is to verify the compliance of the treaty and the storage of the data we receive. For this very reason, the NDC has a large amount of data available to be used by the scientific community. The problem is that this is not very well known today. To solve this issue, it started the Scientific Promotion Programme (SPP), whose objective is to develop data processing capabilities to promote their use in scientific research and to promote the diffusion of the CTBT and its benefits to our community. It offers opportunities to sign agreements with scientific institutions and ensure that this data is being used for pacific and civil purposes and not let its potential be neglected, because around the world, the potential of the IMS data to the promotion of science has been proven. This paper is about the steps followed to develop the SPP and the obstacles encountered during the process (for example: COVID-19) and the aspects that were identified and improved due to this programme at the Chilean NDC.
Promotional text: The main objective of this abstract is the scientific development through data availability for test ban verification and also cooperation with the scientific community to support national needs, exchange of knowledge and ideas between the National Data Center and this community.

P5.3-288 – Improvements of Data Analysis and Capacity Building by NDC-Costa Rica Using IMS Stations and Advances in Updating NDC in a Box Programs

Author: Hairo Villalobos[1]
[1]*Observatorio Vulcanologico y Sismologico de Costa Rica (OVSICORI), Costa Rica*
Corresponding Author: hairo.villalobos.villalobos@una.cr

In recent years with the installation of the NDC-Costa Rica since 2010, improvements have been made in advances in data analysis by CTBTO tools to the states party of the treaty. On the part of the NDC-Costa Rica, the real-time inclusion of IMS seismic stations and OVSICORI local seismic stations for monitoring local, regional, global seismic and infrasonic events automatically through SeisComp 3 acquisition system included in the NDC-in-a box. With the different trainings by CTBTO, some analysis of events data has been carried out, such as: explosion in the Port of Beirut (2020- 08-04 15:08 UTC) where IMS stations were used: I26DE, I4.2PT, I11CV, I17CI, I48TN (infrasound), BRTR, IDI, ASF, EIL, MMAI (seismic) and Stromboli Volcano eruption event in Italy (2019-07-03 14:45 UTC) through infrasound stations: I26DE, I37NO, I42PT, I48TN. In addition, in recent years all data analysis programs such as Geotool, DTK-GPMCC, DIVA, Webgrape, SeisComP 3 have been updated to be accessible to NDC-Costa Rica users for data analysis.
Promotional text: Increased infrastructure and data analysis capabilities at NDC Costa Rica.

P5.3-314 – Seismic Hydraulic Diffusivity: A Tool for Geothermal Exploration

Author: Magdalene Wangui Wanyaga[1]
[1]*Marimant Geoexperts Ltd., University of Nairobi, Kenya*
Corresponding Author: maggie.wanyaga@yahoo.com

The seismic hydraulic diffusivity is investigated to examine the implications fluid circulation has on the seismic activity at a

geothermal prospect. The effect that fluid circulation has on the seismic activity is achieved by estimating the seismic hydraulic diffusivity from a source that originates from a point where the pore pressure propagates from for a distance (r) and time (t) from a single source that initiated the seismic swarms to each earthquake in the swarm. To achieve this aim the following objectives are satisfied; The location of hypocentral locations to outline the seismic event location and correlate them with the causative faults, determining the focal mechanisms to establish the style of faulting and fault plane orientation and to estimate the seismic hydraulic diffusivity to establish the source properties in the causative faults using the following formula; r^2= *43.14*D*t where D is the seismic hydraulic diffusivity. To achieve this a dense seismic network is required, in most cases due to the cost limitations just a few stations are set-up. The data from the seismic IMS stations can be used to improve the quality of data as it adds up to the seismic network and also improves results accuracy.
Promotional text: Geothermal Prospecting using the Seismic Hydraulic Diffusivity and IMS seismic data usefulness.

P5.3-319 – Communication and Public Awareness

Author: Jenifer Mackby[1]
[1]*Federation of American Scientists (FAS), USA*
Corresponding Author: jmackby@fas.org

This presentation will examine the extensive efforts of the CTBTO Technical Secretariat to advance public awareness of the Treaty, and will explore what NGOs have done to further this effort. Most important, it will investigate the avenues that academics, NGOs, and scientific experts can pursue, in particular in cooperation with each other and with respective governments. The CTBTO has established an impressive Group of Eminent Persons and Youth Group; outside, in civilian society, more must be done. Academics, NGOs, and scientific groups can pursue through Coalitions (such as one formed by this author) educational panels, workshops, speaking engagements, at meetings and major international conferences. Their efforts can help exert pressure on governments to ratify the treaty. For example, a U.S.-China symposium organized by specialized, highly recognized thinktanks, NGOs and academics in both countries, would attract considerable attention and could find a receptive audience among government policymakers regarding the reasons for ratification. Although ratification in the U.S. depends on the U.S. Senate, the Biden Administration likely will have a more positive view of the CTBT than the previous administration. Also, while the G7 has supported entry into force of the CTBT, the Treaty is not expected to be a central point of discussion at the NPT Review Conference as it used to be.
Promotional text: How scientific experts and academics can promote the CTBT.

P5.3-447 – Nepal in the Arena of the CTBT

Author: Deepak Raj Shah Shah[1]
[1]*Tribhuvan University, Nepal*
Corresponding Author: emiratescity964@gmail.com

Nepal is a peace loving country and signed Nuclear Non-Proliferation Treaty (NPT) in 1970. Nepal became a Signatory of Comprehensive Test Ban Treaty (CTBT) in 1996 with the commitment of using nuclear energy in improving human health, world peace and prosperity and security - not for military purposes. The Nepalese Government has recently passed a law on Radioactive Material (usage and regulation) Act 2020. It has now opened the door for the peaceful use of nuclear applications for the benefit of the country under guidelines of International Atomic Energy Agency (IAEA) as being a Member State of the IAEA. Next, Nepal is surrounded by several nuclear installations of neighboring countries and is always at the risk of nuclear threats that may occur in its neighborhood. In this context, Nepal can benefit from IMS Laboratories under CTBTO's network especially in monitoring seismic activities and radionuclide monitoring. In this run,

after being motivated through participation in the conferences of National Youth Council (NYC) under the Ministry of Youth and Sports, Government of Nepal. It is the right time for the government to engage youths in the activities of the CTBT. It is necessary to link NYC with the CTBT to carry out CTBTO's mission.
Promotional text: Nepal is a signatory of both NPT and CTBT. Nepal Government has recently passed the Radioactive Material Act 2020. Nepal is surrounded by several nuclear installations of neighboring countries and is at the risk of nuclear threats that may occur and needs assistance of CTBT.

P5.3-463 – MEPhI Science Diplomacy Club: Building Bridges

Authors: Anastasia Kulikova[1]; Varvara Belikova[2]
[1]*Institute of International Relations, Moscow, Russian Federation*
[2]*Moscow Engineering Physics Institute (MEPhi), National Research Nuclear University, Moscow, Russian Federation*
Corresponding Author: norska862@yandex.ru

A central tenet of MEPhI Science Diplomacy Club (SDC) activities is building bridges in the field of scientific and technological cooperation. The Club aims to construct an intergenerational dialogue by cultivating good working relations with high-profile experts in the field of non-proliferation, disarmament and nuclear test ban. The cornerstone of SDC policy is building educational and scientific bridges by providing a platform for youth from all over the world. The Science Diplomacy School "The NPT: Preserving the Legacy", the II UN Security Council Model and Presentation Contest "My vision of the CTBT 2026" are prime examples of bringing students and experts from different profiles and raising awareness about current problems and pressing challenges. In addition, SDC maintains close ties with pre-university students by actively participating in summer practical seminars. It also attaches great significance to engaging female students with proactive attitude in its activities. It's time to make a difference and empower women to get to grips with science diplomacy issues. So, MEPhI Science Diplomacy Club opens up great opportunities for youth to network, share knowledge and exchange experiences.
Promotional text: MEPhI Science Diplomacy Club is a deep dive into intermeshing of science and diplomacy, a chance to raise cross-discipline awareness and a great opportunity to network, share knowledge and exchange experiences!

P5.3-530 – Integrating Real Time CTBTO and Local Seismic Data Using SEISAN

Authors: Peter Henrik Voss[1]; Tine B. Larsen[1]; Lars Ottemöller[2]; Jens Havskov[2]
[1]*Geological Survey of Denmark and Greenland (GEUS), Denmark*
[2]*University of Bergen, Bergen, Norway*
Corresponding Author: pv@geus.dk

This presentation gives examples on how to process and analyse data obtained in realtime from the IMS through the newly developed SeedLink service available on the Global Communications Infrastructure (GCI), using the seismic analysis software package SEISAN. Furthermore, we show how to integrate sensor data and metadata and event parametric data from the CTBTO with locally collected data. SEISAN is used in more than 30 countries mainly at smaller seismic networks or by students or researchers, for processing data from permanent or temporary seismic networks and at a number of NDCs. SEISAN runs on both Windows and Linux and is freely available and open sources (see http://seisan.info). The examples include guides for: 1. Simple configuration of IRIS slarchive software for handling the SeedLink connection and local storage of the realtime data feeds from the IMS in SDS or BUD format. 2. Configuration of SEISAN for analysing data from the SDS in automatic and manual modes. 3. Merge IMS sensor metadata with the SEISAN database. 4. Create local versions of the IDC REB, SEB, SEL, etc. bulletins in SEISAN databases. Signals from teleseismic and local/regional events

are used in the examples using the SEISAN virtual network functionality to include IMS data.
Promotional text: We present methods to integrate CTBTO seismic realtime data with local data, which will enable NDCs to improve nuclear test monitoring, using the newly developed SeedLink service available on the GCI and IDC bulletins.

P5.3-569 – A Book Showing the Importance of an NDC in Brazil for Its Better Participation in the Verification Regime of the CTBT

Authors: Lucas Barros[1]; Brandow Neri[1]; Juraci De Carvalho[2]; Darlan Fontenele[1]
[1]*Seismological Observatory, University of Brasilia, Brazil*
[2]*Enki Projetos de Engenharia, Goiânia, Brazil*
Corresponding Author: lucas.v.barros@gmail.com

Brazil does not have its NDC yet, but its creation has recently been discussed and, to contribute to these discussions, we have written the book The Brazilian Participation in the verification of CTBT, which presents the importance of an NDC, the advantages obtained with its creation and demonstrated importance of CTBT in the control of nuclear weapons and in the construction of a solid social scientific knowledge base, through applications of the IMS data. Brazil participates in CTBT with three technologies (seismic, infrasound and Radionuclide). The book presents the locations of the last nuclear test carried out by RPDK and the accidental explosion in Beirut. There are several benefits for Member Countries with an NDC: access to raw and/or processed data; access to training and capacity building; access to software and technical support; access to a protected website that offers a platform for discussions and exchange of confidential information. By accessing the data of this worldwide network, Brazilian scientists will be able to develop studies and research in all areas of knowledge related to natural and man-made phenomena observable and measured by this worldwide IMS network. In this work we present the main subjects treated in the book.
Promotional text: The book was written to show the importance of an NDC in Brazil in order to better comprise with the CTBT.

P5.3-578 – CTBTO Youth Academy of Sciences

Author: Kseniia Pirnavskaia[1]
Co-author: Evgenii Afanasev[2]
[1]*Korea Advanced Institute of Science & Technology (KAIST), Daejeon, Republic of Korea*
[2]*Moscow State University, Moscow, Russian Federation*
Corresponding Author: pirnavskayakd@gmail.com

This is the research and educational project for CYG members, which involves them in the CTBT research. The participants will work in groups of 4-5 people. Their research topic may include Verification Issues, Article XIV, CTBTO in the context of the nonproliferation regime, Science diplomacy, CTBTO and climate change, non-nuclear related applications of the IMS, et cetera. Each group will have a scientific supervisor from the GEM to bridge the younger and more experienced generation. The resulting papers are to be published in the Newsroom magazine, CTBTO web site and other platforms to revitalize discussion around the CTBT in the scholar's community be the voices of the young generation. Steps: 1) Pre-orientation online lectures on advanced issues related to the CTBT; 2) One-week online seminars on the CTBT key challenges to determine what kind of research is currently relevant and necessary to be conducted. The GEM members are involved in these seminars as speakers and mentors as they are to become research advisors of research teams; 3) One and a half to two months of research work of the research groups; 4) Publishing the results. Presentation of the results during the SNT or SDS in the presentation or poster sessions. The project intends to be an annual initiative.
Promotional text: The CTBTO Youth Academy of Sciences aims at developing and boosting the research in the fields related to the CTBT by being a convenient framework for young researchers. The results will bring back the CTBT on academic and research plate at local, regional, international levels.

P5.3-580 – Pathways Forward: Positioning the CTBT Among Other Arms Control Treaties

Author: Brenna Gautam[1]
[1]*Georgetown University, Washington, DC, USA*
Corresponding Author: bmg81@georgetown.edu

Due to stringent entry into force provisions, the Comprehensive Test Ban Treaty (CTBT) has yet to enter into force, despite a provenly effective comprehensive verification regime and widespread support. Meanwhile, the Treaty on the Prohibition of Nuclear Weapons (TPNW)–a more aspirational treaty with a broader scope and lower entry into force requirements–received enough ratifications to enter into force on October 24, 2020. Among other provisions, the TPNW prohibits the development or testing of nuclear weapons: language reminiscent of, though not identical to, prohibitions contained in the CTBT. This e-poster presentation explores how the current landscape of arms control treaties, including the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and the TNPW, affect the CTBT. It assesses: what are the legal obligations related to nuclear weapons testing under various arms control treaties? In what ways do the treaties reinforce one another? If one treaty poses a risk of undermining the CTBT, how can that risk be addressed, resolved, and transformed into an opportunity? In seeking to answer these questions, the presentation will incorporate the author's legal interpretation of treaty text, the results of expert interviews, and comparisons drawn from other areas of international law with complicated treaty landscapes.

Promotional text: As the global conversation on arms control continues to evolve, reflecting new developments in treaty regimes, the CTBT must remain relevant. This presentation contributes to the SnT2021 objectives of education, communication, and public awareness of that relevance.

P5.3-617 – Importance of the National Data Centres (NDCs) in the Ratification of the CTBT

Author: Didier Birimwiragi Namogo[1]
Co-author: Arsène Sadiki[1]
[1]*Goma Volcano Observatory, Democratic Republic of Congo*
Corresponding Author: didiernamogo02@gmail.com

Some countries have signed the CTBTO nuclear test ban treaty but are reluctant to ratify it. This can have several causes: Either their selfish aspect which can lead them to do not accept a total control by the preparatory commission of CTBTO, or the diplomatic relations are not very well strengthened between CTBTO and these countries. We believe that the installation of National Data Centers (NDC) in these countries can be a necessary tool to gradually bring them to the ratification of the treaty. The National Data Center promotes: continuous exchanges between the signatory country of the treaty and CTBTO; strengthening diplomatic relations between CTBTO and the country. With the National Data Center, CTBTO has the possibility of organizing scientific trainings and capacity building activities in these countries in relation with the verification regime. The delegates of CTBTO will therefore be able to go to these countries and meet there scientific and political figures who are in the position of decision-making. Such continuous exchanges can lead to very strong diplomatic relations that can push these countries to ratify the treaty.

Promotional text: Since the ratification of the treaty is a crucial element for it to enter into force, it is essential to seek the various diplomatic strategies which can help CTBTO to bring certain important countries to this ratification. This abstract helps to increase ideas for CTBTO.

P5.3-655 – Open Day at IMS Stations PS19 and IS26 in the Bavarian Forest

Authors: Gernot Hartmann[1]; J. Ole Ross[1]; Lars Ceranna[1]
[1]*Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany*
Corresponding Author: ole.ross@bgr.de

The Primary Seismic Array PS19 GERES and the Infrasound Array IS26 are located in the Bavarian Forest and are operated by the Federal Institute for Geosciences and Natural Resources (BGR). From 2017 to 2019 extensive GERES refurbishment and recapitalization construction works were performed in the area which also had an impact for local population and tourists as cabling exchange disrupted hiking trails. After completion BGR organized an Open Day for the local population and tourists on 25 August 2019. Besides the chance to see the station elements, a comprehensive exhibition with information kiosks about CTBT monitoring, seismicity, infrasound sources and many other topics BGR is engaged with was provided. In front of the facility building a little folk festival with regional food and drinks as well as traditional brass music took place. During the day around 600 people visited the site at a remote place which seems kind of mysterious for the normal population. But after the open day they knew more about the purpose of the facility and the whole IMS and how monitoring works. Parts of the exhibition were also shown several weeks later when Vienna based diplomats were invited to visit the station site and facilities.

Promotional text: Station visits for the public or diplomats enriched with an information programme about the CTBT and its monitoring regime give a extrremely valuable hands-on experience!

P5.3-681 – Outreach and Education Through Museums and Cultural Centres

Author: Cristopher Allan Cruz Colorado[1]
[1]*Santa Monica College, CA, USA*
Corresponding Author: cristophercross4@gmail.com

The creation of the CTBTO Youth Group is just one example of successful outreach and education being made accessible for individuals not already involved in nuclear/security circles. The entry into force of the Treaty is not just dependent on high-level talks but also influenced by civil-society. This is where museums, cultural, historical, and scientific centers are necessary for the communication of the CTBTO, the Treaty, etc. into the public consciousness. Such examples already exist to talk about nuclear testing and climate change (i.e "Godzilla: A Living Atomic Bomb" & "Nuclear Contamination and Climate Change" by Natural History Museum of Los Angeles County x The Los Angeles Times) and natural radiation (i.e. "Radioactivity in the Natural World" by Naturhistoriche Museum Wien). It would be in the organization and the treaty's best interest to explore new avenues for awareness and promotion as these learning centers are inclusive and non-discriminatory; possibilities of collaboration include but are not limited to: side events/panels, youth programs, exhibits (temporary and permanent).

Promotional text: The idea is to connect with other educative platforms for promoting CTBTO in non-nuclear civil society areas (i.e. Climate) and provide a new avenue for possible collaboration and awareness; this is a new innovative way to tackle the lack of awareness and promotion.

P5.3-682 – CTBTO Youth Group as a Prime Model of Track 2 Diplomacy: United in Science

Author: Marzhan Nurzhan[1]
[1]*Parliamentarians for Nuclear Non-Proliferation and Disarmament (PNND), Czech Republic*
Corresponding Author: marzhan2107@gmail.com

CTBTO Youth Group represents a unique platform of almost 1000 members from diverse backgrounds, connecting science and policy in an interdisciplinary way. The platform provides opportunities through nuclear disarmament and non-proliferation education to involve its members in various track 2 diplomacy channels creating a safe space for active engagement, learning and exchange between peers coming from nuclear- and non-nuclear weapon states. This special type of interaction is possible through different dialogue possibilities available for the members, such as citizen diplomacy, science diplomacy, intergenerational cooperation and citizen journalism – fostering peace and collaborative atmosphere. Technological aspects of the CYG include the website with e-learning resources, connection via webinars and social media. These tools help to expand the network outside of nuclear field and attract more interest in the importance of banning nuclear testing, demonstrating support using a variety of means and contributing for the entry into force of the CTBT, highlighting its verification regime along with the scientific benefits.

Promotional text: CTBTO Youth Group: Citizen diplomacy in action with the use of technologies. Explore more on how CYG acts as a track 2 diplomacy channel which fosters more peacebuilding and security initiatives within and beyond the network.

P5.3-685 – CTBTO Youth Group Communications Model

Author: Valeriya Korotchenko[1]
[1]*National Research Nuclear University MEPhI, Moscow, Russian Federation*
Corresponding Author: korotchenko.valeriya@mail.ru

The CTBTO Youth Group (CYG) was launched in 2016 and since then has around 1000 members. But this membership would not have been possible without effective and proper communication among members and with the CTBTO staff. The objective of the paper is to share successful communications model of the CTBTO Youth Group. The results suggest that this experience could be helpful for other youth organizations and further development of the CYG. Initially, the Group has a Coordination Team that represents the interests of the members and serves as the contact point between the CTBTO representatives (CYG Task Force) and all CYG members. Secondly, it has a CYG portal and social media accounts with the latest news and updates. Likewise, the CYG has a Newsletter that provides its members with information on recent and upcoming events and opportunities, as well as the articles on the CTBT-related topics. Next, Coordination Team members have a regular call with CTBTO staff to discuss strategies and events organization. Moreover, SnT and SDS serve as the platform for CYG members to meet in person and come up with the ideas on the CTBT's and CYG's promotion.

Promotional text: The paper highlights the CTBTO Youth Group's successful communication model thanks to which CYG successfull grows and therefore broadens the engagement of young scientists in working in test ban monitoring as well as young diplomats promoting science diplomacy.

6.6 Awards: Best Oral Presentation, Best Poster Presentation and the European Union Star Award

Three awards were announced at the closing session of the conference. The winning presentations were chosen on the basis of a popular vote carried out electronically on the vSnT2021 platform and an approval process by an expert committee. The awards were:

- Best Oral Presentation: O3.2-482 – A High Resolution Laboratory Based Beta–Gamma Coincidence Spectrometry System for Radioxenon Measurement, by M. Goodwin et al. (AWE Aldermaston, Reading, United Kingdom)
- Best Poster Presentation: P1.1-401 – Characterization of the 4 August 2020 Beirut Explosion from the Infrasound Component of the IMS Network, by J. Vergoz et al. (Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France)
- European Union Star Award: P1.1-064 – Nyepi Day Impact on Weather Parameters Measurement at Synoptic Observation Stations in Bali, by I Putu Dedy Pratama et al. (Indonesian Agency for Meteorology, Climatology and Geophysics, Indonesia)

O3.2-482 – A High Resolution Laboratory Based Beta–Gamma Coincidence Spectrometry System for Radioxenon Measurement

Authors: Matthew Goodwin[1]; Ashley Davies[1]; Richard Britton[2]; Steven James Bell[3]; Sean Collins[3]; Patrick Regan[4]; Robert Shearman[3]
[1]*AWE Aldermaston, Reading, United Kingdom*
[2]*CTBTO Preparatory Commission, Vienna, Austria*
[3]*National Physical Laboratory (NPL), Teddington, United Kingdom*
[4]*University of Surrey, Guildford, United Kingdom*
Corresponding Author: matthew.goodwin@awe.co.uk

GBL15, the UK's noble gas certified Comprehensive Nuclear-Test-Ban Treaty (CTBT) radionuclide laboratory supports the International Monitoring System (IMS) through measurement of environmental radioxenon samples using beta-gamma coincidence spectrometry. GBL15 currently utilizes a system comprised of NaI(Tl) photon detectors and plastic scintillator electron-detectors to measure coincident emissions from the four radioxenon isotopes of interest: Xe-133, Xe-135, Xe-131m and Xe-133m. A high-resolution electron-photon coincidence detector system comprising of high purity germanium (HPGe) detectors and a PIPSBox detector demonstrates improved discrimination between signals and less interference compared to the current system. The minimum detectable activities (MDA) and coincidence detection efficiencies for the radioxenon isotopes of interest have been quantified.

P1.1-401 – Characterization of the 4 August 2020 Beirut Explosion from the Infrasound Component of the IMS Network

Authors: Julien Vergoz[1]; Christophe Millet[1]; Yoann Cano[1]
[1]*Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France*
Corresponding Author: julien.vergoz@cea.fr

The 4 August 2020 tragic Beirut ground truth explosion is of great interest to test the infrasound component of the IMS network, especially in terms of localization accuracy and energy estimation. Although the event was detected by five infrasound IMS stations located from 2400 km (I48TN, Tunisia) to 6200 km (I11CV, Cape Verde), the early location capability from such a sparse network remains limited. Indeed, the spatial distribution of the remote detecting stations tainted by variable background noise levels, coupled with the relatively high uncertainties associated to the atmospheric parameters in the middle atmosphere, make the accurate localization estimation of such medium size events very challenging. We will show in this presentation that even if meteorological institutes can now provide high spatial and time resolution operational products (1h in time and 0.25° in space) at a global scale up to 80 km altitude, the final localization uncertainties remain quite high using infrasound-only data. Examples of full-wave modelling performed from ECMWF analysis and forecasts products, that the IDC distributes to Member States, will be shown to illustrate that point. Such model effects on energy estimation will also be quantified and discussed.

P1.1-064 – Nyepi Day Impact on Weather Parameters Measurement at Synoptic Observation Stations in Bali

Author: I Putu Dedy Pratama[1]
Co-authors: Pande Komang Gede Negara[1]; Putu Eka Tulistiawan[1]; I Ketut Sudiarta[1]
[1]*Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), Jakarta, Indonesia*
Corresponding Author: checkmate_mail@yahoo.co.id

Nyepi is a rare activity in the world that only exists in Bali, where all of human outdoor activities stop for a day. This study used Nyepi to measure its impact on changes in weather parameters measurement in Bali. The purpose of this study is to see the effect of Nyepi on the ratio of daily average temperature to duration of solar radiation as well as daily average air humidity at four synoptic stations in Bali. The data that we used are daily average air temperature, duration of solar radiation, and average air humidity from 1999-2020 on Nyepi. As a comparison, we used data from 2 days before and after Nyepi. Based on 22 years of data at the four location points, we obtained that the air temperature in the 5-day range fluctuates and shows a trend of decreasing daily average temperature during Nyepi for all stations. As for the daily average air humidity, the effect of Nyepi is only visible at the Ngurah Rai Meteorological Station as an increase. The average temperature to sunshine ratio during Nyepi, 2 days before and after Nyepi showed that the lowest ratio occurs at Denpasar Geophysical Station and Jembrana Climatology Station.

7 Relevance to CTBTO Activities and Verification Science

7. Relevance to CTBTO Activities and Verification Science

This chapter summarizes the conference highlights with a special focus on issues that have specific potential relevance to future CTBTO activities and verification science. Unlike previous chapters, it brings together points raised under different themes and topic presentations, Invited Talks and panel discussions. It is organized according to subject matter and structured as follows:

1. Sensors and Measurements
   - Radionuclide Technologies
   - Seismic Sensors
   - Infrasound
   - Hydroacoustic Technologies
   - Calibration
2. Power Systems, Data Handling and Communication Systems
3. Maintenance
4. Performance Evaluation and Optimization
5. Resilience of the CTBT Monitoring Regime: The COVID-19 Pandemic
6. Propagation of Signals
7. Atmospheric Transport Modelling
8. Radionuclide Background
9. Processing of Radionuclide Signals
10. Processing of Seismic, Hydroacoustic and Infrasound Data
11. Historical Data and Events, Event Physics and Screening Methods
    - Historical Event Data
    - Announced Nuclear Tests by the Democratic People's Republic of Korea
    - Source Physics and Modelling
    - Screening Methods and Event Parameter Determination
    - Explosion at the Port of Beirut in Lebanon (4 August 2020)
    - Bulletins and Event Catalogues
12. On-Site Inspection
13. Civil and Scientific Applications

7.1. Sensors and Measurements

It is vital that the PTS stays abreast of new developments related to all sensor types in order to maintain its high performance level, ensure network sustainability, and safeguard and improve Treaty verification capability. Panel J04 discussed new generation sensors that may already be available as well as innovative efforts for future developments. Among the topics of discussion were networks of infrasound sensors, combined rotational and directional seismic sensors, modular design hydroacoustic hydrophone stations, science monitoring and reliable telecommunications (SMART) underwater cables and sensors, fibre-optic seismometers and hydrophones, and improved concepts for radionuclide particulate stations and next-generation noble gas systems. Sensors were also addressed under the dedicated Topic 3.1, as well as in presentations under other topics. Contributions that relate to calibration and maintenance of sensors and stations are discussed in specific subsections below.

Radionuclide Technologies

Currently, most new sensors are in the field of radionuclides. Several next-generation xenon measurement systems with improved detection capability are close to deployment and undergoing calibration, validation and acceptance testing (e.g. MIKS, Xenon International). Two systems have passed the acceptance process successfully (SAUNA III, SPALAX NG). The first SAUNA III system went into operation in September 2021, soon after the SnT conference. During SnT2021, presentations O2.4-510, P3.1-512 and P3.2-518 showcased work on SPALAX NG and future developments of noble gas detection systems.

P3.1-434 reported the results of testing of the upgraded detection system of the MIKS complex prototype, while P3.1-616 and O2.4-138 reported on the first phase of acceptance tests of Xenon International. Results of testing the world's first radioxenon array were reported in P3.1-375. The array consists of five SAUNA CUBE units, placed 200–500 km apart.

Panel J04 and Invited Talk I04-717 highlighted future developments of radionuclide sensors. Deployment of the new systems into the IMS will take place over the next 15 to 20 years, resulting in much improved sensitivity for the detection of xenon isotopes. Future improvements are likely to focus on reducing electricity consumption and footprint while preserving or improving performance. During the Invited Talk, it was suggested that considering the network as a single measurement system would open the horizon for many improvements that can still be made, with respect to measurements as well as data analysis (see below).

The technology used for the collection of particulate radioactivity is well established and robust, but largely increasing air volume requires a technology change. P3.1-669 discussed the integration of an electrostatic precipitator into RASA 2.0 for radionuclide particle collection. P3.1-299 discussed the integration of a next-generation automated air sampler in Cinderella G2. Work on materials for improved adsorption of xenon, such as metal exchanged zeolites relevant for uptake and purification performance, was described in O3.1-316 and P3.1-670.

P3.1-303 presented test implementation of a coincidence detector system for the measurement of particulate samples at the CTBTO Test Station in Vienna. A novel cadmium zinc telluride detector was presented in P3.1-309. Next-generation gamma–gamma coincidence measurements have the potential to significantly improve the confidence of detection of particulate radionuclides that are relevant for nuclear explosion monitoring purposes. P3.1-312 and P3.1-187 described prototype development and experiments.

O3.2-482 compared the performance of different xenon detection systems with high and low resolution for beta–gamma detection. The laboratory plans to evaluate a combination of low resolution gamma–high resolution beta, offering high detection efficiency for gamma radiation and good separation of beta/electron emissions. P3.1-216 described the development of a silicon beta cell for use as a potential modular replacement for the next-generation Xenon International system. Silicon is the leading candidate for future beta cell material due to its much improved energy resolution compared with plastic scintillators (factor of ~3x). The beta cell utilizes four silicon detectors as opposed to the one channel plastic scintillators, which will necessitate data acquisition modifications.

Seismic Sensors

Few contributions addressed developments in seismic sensors on land. Rotation seismometry sensors that might contribute to the quality of the IMS seismic network were discussed in P3.1-180, which focused on metrological aspects in this developing field. P3.1-666 described a fibre-optic gyroscope for the measurement of rotational ground motion. P2.1-162 suggested using dedicated portable rotation sensors for seismological applications to improve the resolution of the isotropic seismic moment tensor by analysing rotational ground motion.

One of the main causes of noise in precise long period seismometry is the temperature fluctuation of mechanical elements of devices and sensors. To reduce such noise, P3.1-393 suggested the use of precision small-sized temperature sensors.

P3.1-102 and P3.1-101 described a new system based on the moiré technique to measure the displacement of suspended masses in seismometers.

P4.1-455 discussed the tuning of IMS seismic stations by optimizing their detection thresholds. The thresholds should be set at optimal values that minimize the miss rate but maintain a high level of precision.

Infrasound

In recent years, an increasing number of low cost infrasound sensors have been developed. P3.1-221 discussed PTS activity to monitor the development of such sensors in order to identify new opportunities for the future of the monitoring system. P3.1-618 described the expansion of the infrasound network by using inexpensive digital condenser microbarographs. P3.3-023 suggested using infrasound sensors in a balloon constellation in the stratosphere.

Adding more sensors to infrasound arrays increases their resolving power, facilitating the detection of weak signals and the identification of multiple simultaneous waves from different directions. P3.1-665 showed that the detail and resolving power of array analyses can be improved dramatically by increasing the number of sensors in the array.

P3.1-520 presented a wind noise reduction system that meets all requirements and topology constraints of the infrasound stations in the IMS network. P3.1-713 discussed the engineering development and evaluation of a coherent continuous infrasound source.

P3.1-128 evaluated the time it takes infrasound sensors to thermally equilibrate under a variety of environmental conditions. This work will help determine suitable procedures for station operators when installing these sensors.

Hydroacoustic Technologies

Sustainment of the IMS hydrophone hydroacoustic network is very challenging. P4.4-276 summarized the ongoing projects of the IMS on solutions for the re-establishment of damaged sections, risk mitigation studies and protective measures. P1.3-270 presented the development of a new modular design concept for next-generation hydrophone stations that has the advantage of making it possible to replace failing components in situ. The first development step in this modular design is a latch mechanism that prevents excessive mechanical load of wet-mate connectors during deployment and allows cables resting on the sea floor to be detached from the modular nodes after deployment. Additional tests are planned to validate the mechanical strength of the latch and optimize the design.

The great potential for fibre-optic technologies, including shallow borehole optical tiltmeters, fibre-optic strain sensors and distributed acoustic sensing (DAS), was emphasized in panel discussion J04. Over the last decade, methods have been developed that use laser techniques with existing telecommunications cables to measure seismic, acoustic and temperature signals with surprising sensitivity, to sub-meter spatial resolution in some cases and with cables longer than 100 km in others. Since DAS is performed along a fibre-optic cable of several tens of kilometres length, it can be used for array observations. In IMS hydroacoustic triplets, the cable between the shore and the first node (21–215 km) contains optical fibres and could potentially be used for sensing seismic signals, temperature and strain. The use of fibres between the nodes can also be considered for similar uses (if nodes were to be connected by fibre connections instead of electrical connections). O3.1-384 discussed the potential for integration of distributed optical fibre sensors into IMS hydroacoustic systems. O1.3-705 provided an update on SMART subsea cables for monitoring the ocean and earth on a planetary scale. P3.1-293 compared observations performed by DAS using a fibre-optic submarine cable with data from co-located hydrophones.

P3.1-396 and P2.3-504 reported on the development and field tests of a new prototype of a geo-hydroacoustic buoy for operational use in Arctic latitudes with distributed drifting ice-class antennas. The sensors were installed in a lake ice surface, forming a seismic array system that operated with high reliability in severe winter conditions. The possibility of placing seismoacoustic arrays on drifting ice floes in the Arctic for monitoring can also be considered.

Calibration

The topic of calibration is cross-cutting among all technologies. It is especially important in a global monitoring system, where contributions from widespread sensors are gathered and fused to reach inferences about events. Calibration issues were emphasized in panel J04, which noted that traceability by national calibration hierarchy, quality assurance and monitoring by comparison measurements is important. A proposal was made to advance the traceability of the IMS sensors to the SI system and the internationally recognized standards. O4.1-213 described the efforts of the metrology community to improve the measurement standards that underpin data quality in CTBT monitoring activities. This aims to foster greater contact with relevant stakeholders, with the objective of establishing primary measurement standards. The described project will also address requirements for reference sensors that link laboratory calibration capabilities to field requirements for measurement traceability.

P3.1-243 presented a web application developed at the PTS for the calibration of geophysical systems that is applicable across all IMS waveform technologies. P4.1-159 presented a tool that extends the standard station interface (SSI) for intuitive execution of instrumental calibrations and review of calibration results. O3.1-467 presented an external calibrator system that is nearing maturity. The integrated infrasound sensor–external calibrator package behaves as a self-calibrating sensor. P4.1-336 described a system that generates comprehensive network intelligence that informs upstream quality assurance efforts. P1.2-631 estimated the occurrence of suspect instrument intervals. It collected time histories of noise measurements obtained near midnight (to eliminate diurnal variations) and found anomalous time intervals that represent 13 per cent of the total inspected time range.

P3.5-250 discussed tools for automatic quality checks of calibration files for radionuclide particulate stations. P3.5-234 examined quality control measurements that are taken to monitor and correct for gain drifts in radioxenon nuclear detectors with a ^{137}Cs source. P3.5-280 described a method to monitor gain changes in radioxenon beta–gamma sensors. While several gamma ray lines can be used, the beta detector does not produce clear peaks. The use of counting statistics from the Compton scatter line gives reliable results.

Presentation P3.5-507 discussed the traceability of analysis results for particulate samples, which is obtained by using standard sources with certificates from source providers. However, it is a pending issue for the traceability of the beta–gamma coincidence analysis. Standard sources are not available for all four xenon isotopes.

P3.1-485 demonstrated the capability to produce gaseous radionuclides for quality assurance and calibration purposes. P3.1-506 presented a ZnS scintillator detector that can determine alpha and beta contamination on large air sampling filters based on pulse shape discrimination. Such system could be integrated in IMS radionuclide stations. P4.1-196 described how to track gain drifts in gamma radiation sensors.

P1.3-284 described a method to improve the estimate of the relative location of IMS hydrophones. Using these refined hydrophone locations, it was shown how location determination of airgun survey sources was improved. This work demonstrates how knowing the accurate deployment position of each hydrophone in the triplet of an IMS hydrophone station is essential to obtaining the accurate location of an event by back azimuth estimation. O3.1-579 focused on the testing of an innovative system for calibrating infrasound sensors.

7.2. Power Systems, Data Handling and Communication Systems

Under a mandate to sustain high data availability throughout the IMS network, next-generation power systems have been designed to strengthen the resilience of IMS stations to catastrophic failures. Presentation O4.3-266 described five standardized IMS power system prototypes that were developed, certified and subjected to thorough factory acceptance testing. The new systems are undergoing long period testing in field conditions. O4.3-514 presented a modular power supply system that is adapted to the IMS network. All of these power systems are equipped with their own state of health information technology system that allows continuous monitoring. P4.3-329 described a solution for the continuous power supply of a seismic station. P4.3-653 presented a model for the incorporation of a stronger energy power system for IMS stations.

Cloud computing has increased significantly over the past several years. Use of the NDC in a box software suite on cloud platforms could expand NDC capabilities and increase their use of IMS data by using cloud resources to perform analysis and data pulls, thereby reducing local bandwidth and infrastructure issues (O4.3-167). Cloud migration was discussed in P4.3-470, including moving new and existing applications to a cloud-ready architecture, creating new cloud infrastructure and services, and incorporating cloud solutions in backup plans.

P4.3-334 described a new configurator developed for standard station interface (SSI), a modular software that collects, signs, buffers, reformats and transmits data using the IDC format. The new configurator has a more user friendly interface and will make it easier to configure SSI over a low bandwidth link. Good database management practices are important to guarantee issuance of products in real time, with the data protected and available in the main database, servers and backups, avoiding unnecessary traffic that overloads the network (P4.3-066, P4.3-140). P4.3-570 gave an overview of how information from a network management system can be used to analyse outages in data transmission to determine the root cause and identify necessary infrastructure improvements. P4.3-558 discussed challenges in using radio frequency links for intra-site communication at IMS waveform stations.

P4.3-414 described the main design changes to the Experts Communication System (ECS). The ECS is a secure, Internet-accessible application that enables registered users from States Signatories and the PTS to access official CTBTO documents and other material. P4.3-445 described a project to create a new email domain for verification data on a segregated infrastructure. The domain @ctbto.int was chosen for the verification systems.

7.3. Maintenance

Despite COVID-19, data availability averaged over all technologies was very high in 2020–2021. Future challenges include an aging IMS network, continued completion and expansion of the network of certified stations under a constant maintenance budget, and no increase in staffing. Several methods were implemented by the IMS Maintenance Unit to improve data availability (O4.4-528). These include equipment standardization, infrastructure improvements, improved equipment sparing, improved hands-on technical training, better documentation and implementation of secure shipping of HPGe detectors.

Sustainment of the IMS hydrophone hydroacoustic network is very challenging. P4.4-276 summarized the ongoing sustainment projects of the IMS through solutions for the re-establishment of damaged sections, risk mitigation studies and protective measures. Innovative modular design solutions to facilitate the repair of underwater components and enhance resilience were described, together with protective measures for onshore electronics. P4.3-267 discussed engineering efforts to mitigate the impact of data loss scenarios of IMS hydroacoustic hydrophone stations by improving onshore digital data handling equipment and adding a local disk buffer. The problem of corrosion is especially acute for stations located near the sea, in high humidity and salty environments. P4.3-571 discussed new types of surge protection with indicators and replacement modules to enable timely replacements, keeping the sites well protected from power surges. P4.3-160 described the comprehensive guidelines and standards for grounding and lightning protection systems at IMS stations. The standard has been implemented at more than 20 IMS stations.

Work on predictive maintenance and state of health monitoring capability continues (P4.4-152, O4.4-209, P4.4-382), with the goal to detect component failures and develop preventive maintenance techniques for IMS stations. Ongoing work aims to develop models to understand state of health data and trends as well as algorithms to integrate predictive monitoring into the state of health data analysis. P4.3-652 proposed the development and implementation of a tool for recording and sharing information about operational problems at IMS stations. A hybrid methodology that combines both data driven and physics based approaches can more accurately predict system failures and extend the prediction window (P4.4-139).

O4.4-135 and P4.4-134 reported on the operation of a temporary IMS seismic station during the major upgrade of a seismic array. With minimal impact on seismic monitoring during the upgrade and at a reasonable cost, the temporary array proved to be a valuable investment.

7.4. Performance Evaluation and Optimization

Operation and sustainment of a global network of monitoring systems poses substantial challenges. Near real time acquisition and forwarding of continuous and segmented data and the subsequent processing and analysis of data must meet and sustain strict requirements for operational data availability, quality and timeliness. The performance critically depends on enabling technologies such as information technology and power systems. Evaluation and optimization of the performance of the CTBT verification system involves factors such as improvements to efficiency and cost effectiveness, reliability and security. Presentations under Topic 4.1 focused on performance evaluation and modelling, but this subject was also addressed in other sessions, panel discussions and Invited Talks.

Speakers in panel discussion J04 and Invited Talk I04-717 commented on the benefits of arrays and increasing the number of sensors. With regard to infrasound sensors, it was stated during the panel that the development of low cost/low power sensors can assist in the implementation of arrays replacing single sensors. Use of large-N arrays will help in wind noise mitigation, and use of advanced signal processing methods can further increase the signal to noise ratio. It was also recommended to increase the use of auxiliary stations, noting that the IMS network is sparse and infrasound signals are directional because of the wind.

It was noted during the Invited Talk that due to the short half-lives of the relevant isotopes, the xenon detection coverage of the network needs to increase. This is a fairly new insight for two reasons. First, the released activity from an underground nuclear test was overestimated when the network was designed. Second, the network coverage was optimized with regard to ^{133}Xe, but ^{135}Xe, the shortest lived isotope, has a much reduced network coverage. This isotope is crucial for source discrimination and event timing. While enhancements of sensor sensitivity have already approached the theoretical optimum, further enhancement of the detection probability can be achieved by replacing single sensors with arrays. In panel J04, it was suggested that after entry into force, the Conference of the States Parties may consider increasing the number of noble gas systems from 40 to 80, which would greatly improve Treaty verification capability.

The COVID-19 pandemic brought unprecedented challenges for the monitoring system in 2020 and 2021. In the face of these challenges, the system demonstrated resilience while remaining functional, thus providing the organization and stakeholders with important lessons that will be useful in the future. Despite the global pandemic, data availability averaged over all technologies was very high in 2020–2021. Future challenges include an aging IMS network, continued completion and expansion of the network of certified stations under a constant maintenance budget, and no increase in staffing. The topic of the implications of the pandemic as a resilience test is further discussed below.

The status of the IDC SHI Reengineering project was presented in P4.1-324. The project goal is to create modernized, open source software for SHI processing, while improving the maintainability and extensibility of the system. The project has been in the implementation phase and under active development since 2019. The alpha tester group is providing test instances of the SHI data processing system that is being developed to participating NDCs.

NDC Preparedness Exercises (NPEs) are a major opportunity for NDCs to conduct exercises based on a scenario investigation for the detection of nuclear explosions in the framework of CTBT monitoring. O4.1-636 detailed the scenario of the NPE in 2019. Two NDCs presented their investigations in P4.1-365 and P4.1-613. For the first time, expert technical analysis was requested from the IDC during an exercise. As part of the NPE process, NDCs discuss the results of the exercise, and lessons learned are used for future NPEs. The NPE 2019 process was delayed due to the postponement of in person meetings of NDCs in 2020 and 2021.

P4.1-113 stressed the need to update the user guide on IDC processing of SHI data (written in 2002) and presented the platform made available as an NDC Forum topic, to take advantage of the considerable collective technical expertise of NDC staff and collect feedback.

An innovative approach to compute source characteristics of infrasound events was presented in O4.1-624. Localizing events is done by combining the usual Bayesian inference with sampling over a metamodel built from an experimental design to update the posterior probability density function. The method can compute source characteristics from signals recorded at several IMS stations. It is efficient and suited for real time monitoring.

O4.1-519 introduced a fully automated stochastic method for calculating the optimal station distribution inside a permanent or temporary seismic network. P4.1-339 used data of relatively small explosions to assess location accuracy and the estimated magnitude of events recorded by the IMS network.

O4.1-121 introduced the Radiation Field Training Simulator (RaFTS), an innovative signal injection methodology. Originally developed for radiation detectors such as IMS radionuclide/noble gas sensors, it can be extended to other IMS technologies by injecting signals reflecting the complexity of a nuclear explosion, thus allowing enhanced training and continual monitoring of performance.

P3.1-115 highlighted the performance of a major upgrade of an infrasound array in a remote location with harsh climate conditions. Over its 20 year period of operation, experience has been gained in operating the array in strong winds, low winter temperatures and springtime flooding. The possibility of remote array control is of prime importance for areas that are difficult to access.

7.5. Resilience of the CTBT Monitoring Regime: The COVID-19 Pandemic

The global pandemic that began in early 2020 put a substantial amount of strain on many systems, and the CTBT monitoring regime is no exception. At the same time, the crisis has proved to be a significant and valuable resilience test that examined the functioning of all systems under considerable stress of various kinds, especially lockdowns and travel restrictions. Various aspects of this issue were addressed under this topic, including the global impact and consequences of the COVID-19 pandemic on the operation and sustainment of the IMS, as well as how station operators, network operators and NDC institutions responded to the situation to mitigate the impact of the pandemic and ensure continuous operation and sustainability of the IMS.

Resilience was addressed in oral and poster presentations under Topic 4.5, as well as in a dedicated panel discussion (J02) and two unique Special Events (M1, M2) where reflections were shared from stations and NDCs, as well as from the PTS. Station operators have faced logistical problems, increased shipping times for spare parts, severe travel limitations, difficulties in the shipment of radionuclide samples for quality assurance/quality control (QA/QC), delays in scheduled station calibrations and unstable communications links. Continuous communication, availability and flexibility in supporting station operators were key to managing the network.

Among the many lessons learned, the following points were emphasized:

- Remote operation of networks has proven to be workable and can even be efficient. However, for maintenance of stations good local support is essential.
- Improving capabilities for remote maintenance and troubleshooting is crucial for the efficient operation and maintenance of stations.
- Local station support is critical for troubleshooting and repairs. Good training of local support staff is essential and substantially reduces travel requirements.
- It is of major importance to develop and implement reliable means of communication with local operators/ station operators and all parties involved in the operation and maintenance of stations. A more flexible approach to communication on different channels has proven helpful.
- Resilient stations require robustness, including high quality sensors, local data storage capabilities and minimum power requirements.
- Good spare parts logistics forms the basis of efficient maintenance, especially when things break. This includes remote spare depots, hot swappable components and thorough pre-testing of spares.
- Preventive maintenance visits and regionalized operation (e.g. in regions of extreme climate) reduce downtime and loss of data availability.
- Remote training, e-learning and troubleshooting videos can be used to overcome travel restrictions.

The COVID-19 pandemic provided station and network operators as well as the PTS an opportunity to test their readiness to respond to network-side limitations and restrictions. Many lessons have been learned, and many solutions have been, or are being, implemented as a result of the crisis.

7.6. Propagation of Signals

Better understanding of the propagation media of all relevant signals is crucial for the monitoring system. The propagation medium – the earth for seismic signals, the atmosphere for infrasound and radionuclides, and the ocean for hydroacoustic signals – determines the timing for the signal arrival at the sensors, affects signal strength and, for waveforms, affects signal shape through dispersion. The attenuation of signals affects their detectability, and the timing affects the possibility of location. Understanding all of these effects is crucial in order to correctly identify the nature of detected events. Three Highlight Talks were given at SnT2021, on the properties of the earth (H1-720), the atmosphere (H3-715) and the oceans (H2-716).

Most monitoring agencies rely on fast, distance-dependent, one dimensional (1-D) earth models to calculate seismic event locations quickly and in near real time. The regional seismic travel time (RSTT) software package, presented in P1.2-120, captures the major effects of three dimensional (3-D) crust and upper mantle structure on regional seismic travel times, while still allowing for fast prediction speed (milliseconds). Validation of the updated RSTT model demonstrated a significant reduction in median epicentre mislocation as well as more accurate error ellipses. The IDC and many NDCs were very active in testing RSTT and made robust contributions that led to significant improvements, particularly in the uncertainty model (J05). Improvements to the RSTT model enable better travel time estimation for regional signals. This in turn improves location estimates for events that include both teleseismic and regional waveforms.

P1.2-369 analysed the difference between the velocity of Rayleigh and Love waves to determine radial anisotropy. O1.2-165 and O1.2-412 analysed P wave data to improve velocity models in the Middle East. Other examples for regional use of RSTT were given in P2.5-086, P2.5-092 and O5.3-072. In P1.2-041, the first continental-scale shear wave velocity (Vs) model of the lithosphere was constructed based on the joint analysis of ambient seismic noise and earthquake data. P1.2-368 presented results from drilling crustal rocks down to 9 km depth and performing active seismic studies.

Three dimensional earth models can improve seismic travel time prediction accuracy, which leads directly to more accurate event locations. Machine learning efficiently emulates travel time calculations, opening the possibility of using state of the art earth models in the operational system (O3.6-118). O3.5-119 proposed consistent comparisons of seismic location accuracy for 2-D and 3-D velocity models that have been developed using different inversion parameters and ray tracing algorithms. Station and phase specific travel time and uncertainty lookup surfaces were generated using a ray tracing algorithm. Lookup tables are much faster than ray tracing, and the accuracy does not seem to be affected.

For infrasound, Invited Talk I03-714 explained that automatically classifying signals and accurately locating events is complex owing to the inhomogeneity and constantly evolving propagation medium, the atmosphere, and the highly changeable and turbulent environmental conditions at recording sites. Middle atmosphere variability is very important, as it controls the infrasound waveguides and is under-represented in models. Long term observations of continuous infrasound sources demonstrated gaps of knowledge in the atmospheric models, such as the need to incorporate gravity waves in the stratosphere.

Noise events in the atmosphere, or 'perturbators', can cause false detection of events. Probabilistic inference methods are often based on priors that are poorly constrained and on extremely simplified propagation models. P1.1-627 introduced a new hybrid framework to derive prior probability models from waveform modelling. Unsupervised machine learning can be used to extract information from the IMS data that can be translated into better constraining automated tasks at the IDC.

P1.3-095 focused on the application of high performance computing for ocean modelling by implementing a code based on solving the frequency domain 3-D parabolic equation. Impressive gains in computation time were demonstrated. P1.3-425 used such capabilities to analyse recorded T waves from an earthquake. DTK-GPMCC was applied to estimate the back azimuths of the T waves. Back azimuth of the signals deviates from expectations based on geodesic propagation paths, possibly due to horizontally reflected and diffracted propagation paths. P1.3-490 discussed 3-D ocean acoustic signal propagation computations for a stratified ocean. P1.3-526 used the combined normal mode–parabolic equation method to carry out modelling of ocean acoustic signal propagation, claiming to be capable of calculating 3-D ocean acoustic signal propagation and signal arrival time at higher acoustic frequencies than models based solely on the parabolic equation. P1.3-408 emphasized the need for awareness of possible local and temporal changes in sound speed in the ocean with the potential to impact medium to high frequency acoustic propagation.

7.7. Atmospheric Transport Modelling

The atmosphere poses a special challenge because of its dynamics and variability. ATM is required to obtain a link between a seismic event and a series of radionuclide detections. Invited Talk Is4-332 explained the implementation of an ATM system with special post-processing routines and the build-up of relevant expertise. The current ATM operational system is based on FLEXPART, a Lagrangian particle dispersion model, and uses global meteorological data. Backward simulation is the method of choice if a source is unknown. In special cases where a source location is known, such as announced nuclear explosive testing by the Democratic People's Republic of Korea, forward modelling is done. Thanks to the optimization of FLEXPART and new ATM servers procured in 2019, a simulation can now be completed within four hours.

To meet the needs of the CTBT verification system, the ATM system of the IDC needs to be validated. Is4-332, O2.4-056 and P2.4-637 described the efforts undertaken in the framework of the third ATM Challenge, an international exercise launched in November 2019 that aims to understand the radioxenon background. The ultimate goal of the latest exercise was to provide an ensemble analysis of radioxenon background levels at IMS stations located in the Northern Hemisphere, which are frequently impacted by industrial emissions. P2.4-563 and P2.4-480 presented comparisons between measured and simulated radioxenon concentrations using ATM and real time stack emission data from the medical isotope production facility in Fleurus, Belgium. P2.4-037 applied a global atmosphere chemistry model to simulate the dispersion and deposition of radionuclides, such as ^{137}Cs, ^{131}I and ^{133}Xe, released from the Fukushima Daiichi nuclear accident. P2.4-335 discussed the effect of the 2020 Chernobyl Exclusion Zone wildfires on the IMS radionuclide station network. P2.4-590 evaluated the potential benefit of multi-input atmospheric transport ensemble modelling for monitoring applications. P4.1-595 presented an investigation on utilizing high resolution backward ATM simulations to locate possible source regions after detections of radioactive substances. P4.1-593 developed a methodology to run hundreds to thousands of paired ATM (FLEXPART) simulations to assess the benefits of using higher resolution models.

It is very challenging to run atmospheric models at microscale resolutions over complex terrain. O1.1-596 and P1.1-650 discussed field experiments to evaluate model performance. The differences between forward and backward sensitivities were discussed.

7.8. Radionuclide Background

It is vital that nuclear explosion signals can be distinguished from natural and anthropogenic radioactivity in the atmosphere. The global background of xenon isotopes has been found to be higher than what was expected when the Treaty was drafted 25 years ago, mainly due to xenon emissions from medical isotope production. The biggest issue for discriminating nuclear explosion signals from the normal radioactivity background in the atmosphere is the high variability of the background in time and in location (Is7-604). The use of data collected at known facilities may prove useful to remove the effect of these sources.

While isotope ratios in the background are generally different from those associated with a nuclear explosion, uncertainties in the interpretation of IMS measurements remain. Being able to identify the source of civil xenon emissions would increase the robustness of verification. P2.4-211 and P2.4-078 described STAX (Source Term Analysis of Xenon), an experimental network of sensors to detect and quantify emissions of xenon isotopes from medical isotope production and other nuclear facilities. P2.4-206 described measurements to better characterize the radionuclide emissions of a nuclear power reactor. The first observations of environmental ^{125}Xe, ^{127}Xe and ^{129m}Xe were reported in O2.4-138. These isotopes have been attributed to a nearby high flux reactor. Implications for IMS systems were presented, and possible mitigation strategies were proposed. Similarly, P2.4-607 investigated radioxenon generated by activation sources such as a reactor or strong spallation neutron source. The case studies give evidence that a spallation neutron source can explain past observations of ^{133}Xe and ^{135}Xe. O2.4-510 presented the analysis of the radioxenon detections observed by the new generation SPALAX-NG system near Paris in 2019. The high sensitivity of the system enabled a large amount of multi-isotopic detections, including ^{133}Xe, ^{135}Xe and ^{131m}Xe. The ATM results showed that observed detections came from the main emitter in Fleurus, Belgium, but also from a local producer of radioelements for medical purposes.

O2.4-709 presented two statistical methods: parametric and non-parametric, that when applied to ^{133}Xe activity concentration measurements allowed for better understanding of the atmospheric background and anomalous values. Examples of the application of these statistical methods were given in O2.4-406, P2.4-260 and P2.4-261. Based on a statistical analysis of variability in the background, P2.4-125 discussed important factors associated with fluctuations due to synoptic weather events, temporal changes in background sources and site specific details related to the placement of IMS stations. More data on the xenon background were provided in P2.4-421, P2.4-551, P2.4-552, P2.4-553 and P2.4-606.

7.9. Processing of Radionuclide Signals

Radionuclide observations made by the IMS are an important part of the CTBT verification regime, as they make it possible to discriminate between conventional and nuclear explosions. In discussion J05, panellists noted that progress in radionuclide processing has been very substantial. It is now possible to use both detections and non-detections to make probability distributions for the original release location and calculate the time and magnitude of the release. Four key questions that still need to be answered in the radionuclide domain were identified: (1) How do we fuse measurements of xenon and aerosols, which behave quite differently in the atmosphere? (2) How do we take the radionuclide background into account? (3) How do we make use of isotopic ratios, for example in a screening tool? and (4) How can we automatically generate a list of associated measurements and produce the equivalent of waveform association?

The biggest issue for discriminating nuclear explosion signals from the normal radioactivity background in the atmosphere is the high variability of the background in time and in location (Is7-604). Radionuclide event screening groups radionuclide detections into categories called “levels” and uses flags to highlight samples that are more likely than others to indicate a possible nuclear test. The possible addition of flags for selected isotopic ratios was suggested. The following suggestions were made to enhance screening for noble gas samples: (1) add a flag of “ATM backtracking to known sources”, (2) add a flag for the isotopic activity ratio of ^{131m}Xe/^{133}Xe and (3) optimize the threshold values for the isotopic ratios. The use of data collected at known facilities may prove useful to remove the effect of these sources. O3.5-343 calculated maps and statistical estimators of network capability for xenon background levels.

Release of activation-generated radioxenon can occasionally be observed at noble gas systems of the IMS and interfere with beta–gamma spectroscopy analysis of radioxenon. O3.5-456 used simulations to test the hypothesis that the isotopic activity ratios can be used as a discriminator for activation or fission. P3.5-235 described a method to calculate the impact of radon on radioxenon detection sensitivity in coincidence beta–gamma detectors. Argon-37 is an important indicator of an underground nuclear explosion, but normal operational releases from nuclear facilities contribute to its atmospheric background. P3.5-483 presented a method for assessing ^{37}Ar emissions from nuclear research reactors looking at an appropriate proxy, such as ^{41}Ar, for which stack release data are available.

Presentations P3.5-507 and O3.5-573 provided an overview of radionuclide analysis methods at the IDC. Potential enhancements of current methods include optimization regression analyses of standard spectra, 3-D fitting and gross counts, and machine learning. Improvements aim to lower the rate of false alarms resulting from under-estimation of decision thresholds. Including uncertainty components related to interference corrections, deconvolution of X ray contributions of xenon isotopes and radon, and estimating the covariances of net numbers of counts between regions of interest for isotopic ratio analysis were also mentioned as possible improvements. P3.5-610 proposed scientific projects to further develop methods for associating multiple samples to the same radionuclide release event and for backtracking to known sources.

P3.5-407 described a Bayesian statistical inference tool to reconstruct the emission source by fusion of radionuclide data and ATM. Trials on real world reconstructions have demonstrated clear and dramatic improvements over standard correlation techniques. P2.4-373 presented an algorithm that could determine the release location and other source parameters by making use of radionuclide observations (both detections and non-detections) and source–receptor sensitivities. P3.5-508 described the use of Monte Carlo calculations of isotopic ratios of fission products, with the aim of trying to assess the time of explosion events under assumed scenarios.

P3.5-278 described the development of algorithms that include interference terms for the four radioxenon isotopes and the radon daughters to reduce biasing and false positives that are caused by large interference radioxenon spikes. P3.5-442 presented a new algorithm for processing beta–gamma coincidence spectra based on the maximum likelihood and non-negative least squares (NNLS) methods, which allows simultaneous processing of the signal in all regions of interest. P3.5-236 discussed a possible technique to mitigate effects of detector gain drifts through the use of a larger region of interest in the isotopic analysis. Improving the sensitivity of radioxenon beta–gamma measurements by optimizing the region of interest limits for each sample was suggested in P3.5-377. Dedicated spectrum analysis algorithms for SPALAX systems were presented in P3.5-300.

O3.6-225 and P3.6-509 proposed a model of beta–gamma coincidence radioxenon spectra classification by deep learning (CNN technique) for pre-screening of CTBT-relevant samples. P3.6-516 applied automatic radionuclide detection using deep neural networks to gamma ray detector data. Experiments on simulated spectra suggest that deep learning methods can achieve a higher F1 score compared with the best performing traditional machine learning models.

P3.5-245 described the development of an automated process for the fusion of radionuclide and ATM data streams that also provides interactive virtual maps for rapid data interrogation. P3.5-026 described a method to classify particulate radionuclide spectra as “likely normal” or “requires scrutiny” that is entirely ignorant of radionuclide science. Accuracy of over 94 per cent was achieved. P3.5-282 proposed a quality scale that will help prioritize samples for analyst review and shorten the review time. P3.5-345 described a system for analysing radionuclide monitoring data that enables automatic acquisition, database storage, automatic processing, interactive analysis and statistical query of IMS radionuclide data.

7.10. Processing of Seismic, Hydroacoustic and Infrasound Data

The theme of data analysis was discussed in the Keynote Talk on the opening day (G3), two panel discussions (J05, J08), several Invited Talks (I01-722, I08-723, Is1-353, Is6-454) and many oral and poster presentations, in particular under Topics 3.5 and 3.6.

Discussions and presentations focused on using machine learning and artificial intelligence, analysis tools, moving from arrival time parameters to full waveform analysis, improving the understanding of uncertainties, data fusion applications and new pipeline paradigms and methods.

The prospects of using artificial intelligence and machine learning methods for data analysis and interpretation were an important topic of SnT2021. Machine learning techniques have the potential to exploit the large amount of data archived at the IDC and improve the accuracy and computational efficiency of both automatic and analysed results, while reducing the analyst workload.

NET-VISA is a physics based generative model of global scale seismology that has recently become part of the operational IDC software. It generates improved automatic event lists, thereby improving the quality of the automatic bulletins and reducing analyst workload. The model and its associated inference algorithm have been deployed by the IDC to generate the VSEL3 bulletin of events, which is used by analysts to generate the LEB. The benefits of NET-VISA were discussed during Invited Talks on the 25th anniversary of the CTBT (I08-723, Is6-454), oral presentation O3.6-400 and several poster presentations (P1.1-158, P3.6-651, P4.1-294, P4.1-330). The model utilizes probability density functions derived from historical data (seismic events reviewed by analysts). At its inception, NET-VISA was created for the association of seismic events, but it now also supports hydroacoustic (Is2-283) and infrasound (Is3-381, P1.1-158) event data. It has been progressively enriched with more and more capabilities, such as interface for analyst review, improvements in the regional velocity model and error ellipses. O3.6-400 described a new module added to the NET-VISA model to obtain more accurate estimates of confidence ellipses with Markov chain Monte Carlo (MCMC) methods. Currently, analysts can alternate between NET-VISA and the current phase associator (see comparison in P4.1-330), and NET-VISA is expected to become the default phase associator.

The NDC in a box software package is developed, distributed and supported by the PTS. It provides NDCs the capability to perform a variety of functions, including receiving, archiving, processing and analysing data from IMS stations. P3.5-392 presented a tool to make standard data files of non-IMS seismic stations accessible by NDC in a box. P2.3-441 highlighted examples of integrating IMS data with local seismic data using SEISAN software. P3.5-584 demonstrated how Generalized-F Detector (Gen-F) was integrated into an existing NDC Detection and Features eXtraction (DFX) detection framework. Gen-F can be directly integrated into the IDC pipeline. P4.1-294 presented the results of testing of the latest release, which contains the NET-VISA associator with SeisComP3.

I01-722 pointed out an important transition in data analysis, which is the move from using arrival times to full waveform exploitation. The traditional method of location based on the time difference between arrival times suffers from several flaws because it is based on a very small portion of the seismograms, uses small amplitude waves, and requires a local model to convert time differences to distance. O3.5-398 used cross-correlation to detect Lg waves to find and locate new seismic events with the help of a sparse temporary seismic network. Using more stations enables better characterization and location, and many more events were identified in comparison with those in the Late Event Bulletin of the CTBTO.

Is1-353 presented possible new applications for expert technical analysis. These include the Parametrical Moment Tensor Estimator (ParMT), which provides depth and magnitude determination through moment tensor estimation, and the Spot Check Tool (SCT), which is based on historical master events. The main component of the ParMT application is moment tensor estimation (MTE), which is a strategy to estimate the depth and magnitude of an event with an unknown source mechanism. Depth is a powerful event screening parameter to distinguish between earthquakes and explosions. P3.5-194 designed a semi-automatic depth estimation tool for events with depths less than 3 km and tested it on waveforms from a series of well-located explosions. Automatic depth determination at teleseismic distance remains a challenge. O1.2-277 proposed two complementary methods to improve signal to noise ratios and automatically identify coherent depth phases.

Spot Check Tool (P3.5-355, P3.5-354) is based on waveform cross-correlation and uses information from historical REB events to apply new detection, phase association and other algorithms and methods. The SCT is under development, and the updated front-end interface will soon be available for basic testing. P3.5-183 attempted to improve the effectiveness of WCC detections using template event metadata and network analysis of corroborating stations. Effective WCC requires templates with broad frequency content to produce reliable single station detections. The coda magnitude method provides stable source spectra and moment magnitudes (Mw) for local to regional events that are virtually insensitive to source and path heterogeneity. The freely available Coda Calibration Tool (CCT) is a fast and easy Java based platform (P3.5-453) that is three to four times less variable than traditional direct wave estimates.

Automatic identification of repeating seismic events such as aftershocks and mine explosions can help to improve the quality of automatic bulletins and reduce the analyst workload (P2.3-356). Diffusion maps algorithms were discussed in O3.6-148 and P3.6-111. In P3.5-198, a dynamic correlation processor (DCP) was used to form groups of similar waveforms. P3.6-326 examined neural network architecture for detecting repeating events using seismic arrays. P3.6-143 applied a paired neural network (PNN) to automatically perform aftershock identification based on waveform similarity. P3.5-561 compared two earthquake detection methods: matched filter and fingerprinting. While the matched filter was easy to implement and precise, the fingerprinting method (comparing the time–frequency signature of signals) was much more efficient computationally.

P3.6-197 demonstrated discrimination between earthquakes and quarry blasts using a committee machine that combined supervised and unsupervised artificial neural networks. P3.6-269 discussed unsupervised deep learning for identifying seismic event classes in signal-rich records. A computational neural network (CNN) was also used in P3.6-541 for the detection of local events under the global sparse seismic network. The principle that the P wave and S wave velocity ratios of local earthquakes in the regional network are consistent was used in the association of seismic phases from multiple stations.

A new development is the SIG-VISA tool (I08-723, Is2-283). SIG-VISA will consider the full waveforms and add to the analysis the consideration of general waveform shape and coda decay rate, superposition of signals, spatial continuity of travel time residuals, repeatability of waveforms, and more. The performed inference naturally yields sub-threshold detection, global beamforming, locations from single-station detections and accurate locations via 'double-differencing'.

Even as artificial intelligence methods become more powerful, an important aspect that was repeatedly discussed during SnT2021 is the need for the models to be physics based so that explainability remains an important aspect of the interpretation process. This topic was discussed in panel J08. Presentation P3.6-131 discussed regularization and semi-supervised learning for seismic event analysis by enforcing consistency over disparate observations in order to produce trustworthy decision confidence and allow the leverage of data where no ground truth is available. The problem of creating data sets for training was discussed in O3.6-205, which proposed a physics based data augmentation method to produce entirely synthetic training data set catalogues for machine learning analysis of long range infrasound signals.

In some areas the IMS seismic network consists of mostly 3-C stations. Unlike array stations, back azimuth estimation for such stations uses polarization analysis, and it can be unstable (Is6-454). BazNet (P3.6-706) is a deep neural network based back azimuth predictor that makes single-station azimuth predictions accompanied by an uncertainty measure. O3.5-462 argued for the exploitation of all three components of fully 3-C seismic arrays to take advantage of the coherency of the horizontal components. For S phases, this has the potential to significantly improve detection and characterization.

The deep neural network tool ArrNet (P3.6-707) can reliably refine the automatically picked arrivals and improve the quality of automatically created event lists and consequently reduce interactive review time. In P3.5-386, higher order statistics were used to improve the signal to noise ratio of single sensor waveforms and the variance of the trace to estimate the arrival time of a signal. P3.5-114 presented an automatic method to pick first arrival points of signals based on the fractal dimension of seismic traces.

The standard processing algorithms Analyst Review System (ARS), Hydroacoustic Azimuth Review Tool (HART) and Progressive Multi-Channel Correlation algorithm (DTK-GPMCC) used at the IDC were employed to estimate the signal back azimuth of underwater explosions (P1.3-546). Back azimuth estimates of both primary and secondary arrivals from HART and DTK-GPMCC were in general consistent. Identification of reflected arrivals can potentially be incorporated in the IDC processing system to improve localization of in-ocean events by IMS hydrophone stations. P1.3-494 evaluated how signals from offshore seismic surveys with airgun array sources can be used to validate theoretical predictions of propagation models. A sample of recorded signals from seismic surveys obtained from historical IMS hydroacoustic data was exhaustively analysed to infer underwater propagation properties.

While each piece of information is useful for verification, the full benefit of multi-technology measurements can be further enhanced by data fusion, where disparate sources of data are integrated into a unified and comprehensive event analysis. P3.5-476 suggested methods to reconcile inconsistencies and improve the inference process. P3.5-127 fuses radio, acoustic and seismic waveforms in order to detect small, above ground explosions. Combined analysis of seismic and infrasound data could lead to significant improvements in our understanding of the processes that simultaneously generate both types of signals (O2.3-130). As some sources are more likely to be detected via seismic signals and others by infrasound signals, co-locating seismic and acoustic sensors can be beneficial. P2.3-116 discussed the discrimination of quarry blasts by applying correlation techniques with a combination of seismic and infrasound data. P2.3-246, P2.3-366 and P3.1-265 analysed explosions utilizing seismic and infrasound data from IMS stations or mobile infrasound arrays.

Waveform data are generally contaminated by noise from various sources. To date, the most common noise suppression methods have been based on frequency filtering. P3.6-124 implemented a seismic denoising method that uses a trained deep CNN model. The denoiser achieved up to ~2–5 improvement in the signal to noise ratio over bandpass filtering and can suppress many types of noise that bandpass filtering cannot. P3.6-615 presented work to develop a new generation of deep neural network that takes advantage of basic universal laws to predict the background infrasound noise. In combination with Bayesian approaches such as NET-VISA, neural networks can enhance the association process.

7.11. Historical Data and Events, Event Physics and Screening Methods

The 25 years since the Treaty opened for signature have been marked by only a few test explosions. This is a great success. However, it raises a challenge in terms of validation of the tools and methods of the CTBTO monitoring network. It is harder to prove that the system is indeed able to identify any foreseeable nuclear test anywhere on the globe when there are hardly any nuclear tests to be detected. Methods need to be validated with a scarcity of ground truth events.

This situation raises the importance of looking at historical data and modelling the response of the monitoring system to such events.

Historical Event Data

The important topic of historical nuclear test explosions data was presented and discussed in panel discussion J03. Historical data are needed from as many different regions and geological characteristics as possible. Signals from tests in the atmosphere, underwater and underground should be preserved. Most ongoing efforts focus on seismic data, as historical hydroacoustic and infrasound data are rare and radionuclide data are sparse. The treasure of historical observations associated with nuclear test explosions is of great value for realistic case studies to validate methods, with the objective of identifying the source of an event that is of relevance for Treaty monitoring. These data can also be used to identify challenges in nuclear explosion monitoring and for training and NDC performance exercises.

Not all relevant data are available, and there are challenges in their preservation and use. Four aspects should be considered regarding historical data: (1) understanding what data is available in a given country and what data can be retrieved and used, (2) data scanning or scanning/digitizing, (3) metadata and (4) delivery to the broader community. Calibration through known event mechanisms is one of the ways to recover the unknown responses of recorded event sensors. Comparison of records obtained by instruments with known and unknown responses helps to understand the unknown response. O2.5-298 and P2.5-297 described the seismic data catalogue on 47 nuclear tests conducted at the Lop Nor site in China between 1964 and 1996. P2.5-594 and P2.5-499 described the recovery and digitization of seismograms from peaceful nuclear explosions (PNEs) conducted by the Soviet Union in a wide range of geological settings and geographical locations. Most are from short-period instruments. Many of the explosions can be used as ground truth events to construct regional seismic travel time curves for regional phases and for station calibration. The amplitude spectral ratios were tested as a discrimination criterion. Historical chemical explosions can also serve as ground truth events for the calibration of regional seismic networks. P2.5-176 described data on large chemical explosions conducted in Kazakhstan during Soviet times. More data on seismic historical events was presented in P2.5-086 and P2.5-089 (Central Asia) and P2.5-181 (Kazakhstan).

P2.5-443 described how applying an interpolation algorithm and examining the frequency recovery of the potential records improved the digitization process of legacy seismograms. P2.5-397 described applying calibration to digitized historical seismograms. Software was developed to convert the originally published yearly station calibration parameters into usable files.

O2.5-481 presented a literature review on atmospheric radionuclide monitoring, covering 35 nuclear tests conducted between 1964 and 1996. Most of these tests occurred in the atmosphere, but nuclear debris from venting of underground nuclear tests was also observed. P2.5-712 described the study of annually laminated sediments (1909–2015) using lake freeze cores. This allowed the reconstruction of caesium, americium and lead fallout history.

P2.2-313 presented information about radioactive contamination near a tunnel portal at the Semipalatinsk Test Site in Kazakhstan as a consequence of underground nuclear testing. This information could contribute to understanding of OSI-relevant observables.

Announced Nuclear Tests by the Democratic People's Republic of Korea

Although the last announced nuclear test by the Democratic People's Republic of Korea was in 2017 (DPRK6), work continues on the analysis of these experiments. O2.1-275 reported on detections at IMS hydrophone stations of primary and tertiary phases from this test. These appear to be the first detections of this kind at IMS hydrophone stations.

P2.1-643 provided a comprehensive overview of how ATM supported the analysis of radionuclide detections from tests in the Democratic People's Republic of Korea. In several cases, measurements of releases from nuclear facilities caused ambiguous radioxenon detections in the aftermath of the tests. There were matching isotopic ratios and fitting atmospheric conditions for only two tests (2006, 2013). Results for two other tests were consistent but not conclusive, with detections of ^{133}Xe only (January 2016, 2017). For two other tests (2009 and September 2016), it was not possible to identify potentially related radioxenon detections.

P2.1-123 performed discriminant analyses combining cross-spectral Pg/Lg and Pn/Lg from regional stations. The analysis was able to separate the cavity collapse from the population of nuclear explosions. However, the distinction between the earthquakes and the cavity collapse is ambiguous. P2.1-371 reported on the development of a rapid and automated full seismic source characterization method that correctly identified all announced nuclear tests by the Democratic People's Republic of Korea.

Source Physics and Modelling

As not all announced underground tests resulted in detected radionuclide signals, it is important to understand the conditions that affect such release of gas and particulates.

O2.4-477 presented the results of a series of highly instrumented mesoscale experiments that provided an opportunity to better understand the interaction between source strength and location, natural variations in rock competency, explosion-induced rock damage and gas migration. Results showed that the influence of geologically weak zones on rock damage and gas flow was comparable to the influence of source strength and location.

P2.4-217 performed microscale studies of the formation of particulate and the transport of gaseous species within a variety of geologic media. P2.4-258 presented a code that was developed for two phase flow, tracer transport and thermal effects through a fractured porous medium under the action of constant or time dependent pressure fluctuations. O2.5-173 described how film footage of historical nuclear tests enabled new analysis of the shock propagation and buoyant cloud rise with material entrainment. Combining such data with an understanding of buoyant cloud rise and cloud stabilization informs entrainment, including the total mass of entrained materials.

The implications of underground nuclear explosion cavity evolution for radioxenon isotopic composition were discussed in O2.1-208. Collapse of the cavity can have a large effect on partitioning of the refractory fission products that are precursors to radioxenon. Realistic assumptions about the state of the detonation cavity produce isotopic ratios that differ from the civilian background more than the idealized standard model indicates, while also predicting reduced quantity of radioxenon available for atmospheric release and subsequent detection. These results can improve the distinction between emissions from a nuclear explosion and the civilian background.

The yield of nuclear explosions is not the direct concern of the CTBTO, but it is still of interest for States Signatories to characterize the capabilities of the IMS network. The fraction of the yield that is transformed into seismic energy affects the determination of yield. As reported in I01-722, in historical test data it was observed that a lot of the energy was absorbed in crushing rocks in the immediate vicinity of the cavity and in the large ring where anelastic deformations occurred due to the explosion. O2.3-141 discussed the dependence of the release of shear waves in explosions on the scaled depth of burial, based on results from a series of Source Physics Experiments (SPEs). A major goal was to identify sources of 'excess' shear, which complicates discrimination criteria. The results establish the importance of joint unloading at distances of several kilometres from the source and raise possible implications for nuclear explosion monitoring.

Screening Methods and Event Parameter Determination

A major challenge for the CTBTO is to distinguish between the vast number of detected natural and anthropogenic events and a possible nuclear explosion. Screening methods have been devised for signals from all technologies of the monitoring network. At times, attributes can be mistaken to yield false positives. P2.3-415 analysed data from the 2018 eruption and collapse sequence of the Kilauea volcano in Hawaii, USA, that reveal collapses that are similar to events following nuclear explosions in the Democratic People's Republic of Korea and the Nevada Test Site.

The initial development of the mb magnitude scale and the mb:Ms criterion for event screening was mainly based on body wave data recorded by standard short period instruments. Today, the IMS consists of a range of both short period and broadband instruments. Event screening can be enhanced by understanding variations in mb measurements and determining if current mb determination methods are optimal. Screening methods that are now in use at the IDC and potentially more robust methods were discussed in P2.3-240.

Information on moment tensors is important for understanding the origin of events (e.g. explosions, natural and induced earthquakes). The calculation of moment tensors for weak seismic events is challenging. P1.2-659 reanalysed methods of inversion of amplitudes of P and S waves and inversion of 3-C full waveforms, complemented by first motion polarities. As pointed out in Is1-353, the intersection of earthquake and explosion populations is an important issue when using the focal mechanism as a screening parameter. This effect is clearly observed in the mb/Ms screening criterion. Depth is a powerful event screening parameter and the main goal of the ParMT application, automatic depth determination at teleseismic distance, remains a challenge: the depth phases (pP, sP) reflected on the free surface are sometimes difficult to determine, especially for events of intermediate magnitude (Mw<5). O1.2-277 characterized uncertainties associated with teleseismic depth determination.

Regarding radionuclide screening, Is7-604 reviewed screening methods for discriminating nuclear explosion signals from the normal radioactivity background in the atmosphere. P2.1-268 described a 3-D analysis method that offers opportunities for event screening and determining the event zero time. Event characterization can be achieved without knowledge about the time of the release from the source, which might be useful for CTBT monitoring purposes. Radioxenon isotopic activity ratios were also analysed in P2.1-601 and P2.1-486.

P2.1-572 discussed uneven nuclear debris 'hot' particle deposition areas, where elevated $^{137}Cs/^{239,240}Pu$, $^{238}Pu/^{239,240}Pu$, $^{240}Pu/^{239}Pu$ isotopic 'fingerprint' values can reveal a nuclear event and assess its source by fusing these values with ATM.

O2.1-061 discussed how machine learning algorithms can be used to classify electromagnetic events as lightning or not lightning with high reliability. Measurements of electromagnetic fields may serve as a means of supporting infrasound signal analysis, as a nuclear explosion is the only electromagnetic pulse source that also produces a long range infrasound signal.

Explosion at the Port of Beirut in Lebanon (4 August 2020)

A special subsection focused on results from the analysis of signals captured following the tragic explosion at the Port of Beirut in Lebanon on 4 August 2020. The explosion triggered seismic, acoustic, infrasound and hydroacoustic signals that propagated through the lithosphere, atmosphere and hydrosphere. The effects of the shock wave were also captured on video. The presentations merged information from various sensors and technologies of the CTBT monitoring system to estimate the yield of the event. Exact estimates from seismic data are complicated owing to the uncertainty of the coupling of the above ground explosion to seismic waves. Most yield estimates were in the range of 0.5 to 1 kt, which is plausible given the reported 2.75 kt of ammonium nitrate as the explosive source, only part of which contributed to the explosion (O2.1-656, O2.1-228, O2.1-191, P2.1-195, O2.1-290, O2.1-656, P2.1-540, P1.1-401, P1.1-137, P1.1-588 and P1.1-672). The ground truth and multi-phenomenon observations allow assessment of the challenges for source localization accuracy and energy estimation. The value of combining data from different technologies was shown, for example by largely reducing the location error if one seismic signal is added to the infrasound signals.

Bulletins and Event Catalogues

P4.1-446 analysed statistics of mostly natural seismicity waveform events processed and analysed over the past 20 years at the IDC and released as the REB on a daily basis since February 2000. It analysed multiple parameters including magnitude for events detected by seismic, hydroacoustic and infrasound stations.

A comprehensive reprocessing of the IMS infrasound database was presented in O1.1-389 and P1.1-399. It covers the period from January 2003 to December 2020, with data from up to 53 stations. The catalogue of coherent signals obtained using the PMCC array processing algorithm permits more accurate signal and source discrimination. The presentation focused on the relation of coherent ambient infrasound to middle atmosphere dynamics. The data products consist of mountain associated wave events, microbarom data, and signals from large fireballs and volcanic eruptions that provide information that is relevant to civil security.

The IMS hydrophone stations provide low background high quality data. An analysis of years of data processed using the DTK-PMCC algorithm detector was presented in P1.3-402. Global association of detections is performed to build automatic events. Locations of low amplitude events were obtained by the accurate back azimuth estimates, simple blockage maps and back azimuth crossings for hydroacoustic stations with two and four hydrophones. These event locations compare well with independent event catalogues and demonstrate the impressive monitoring capability of the relatively few IMS hydrophone stations.

P2.5-086 and P2.5-089 reported on the creation of a unified seismic bulletin of Central Asia, using earthquake data from 1949–2009. Analog seismograms were converted into digital format. The unified bulletin contains over 10 million arrivals, with preliminary relocation of more than 350,000 events. The project fills a considerable portion of a data gap for the region; increases the accuracy of event parameters; preserves unique, perishable archival data; and supplements ISC bulletins with new data for the region.

P1.2-155 examined the consistency between the IDC and the International Seismological Centre (ISC) magnitudes for earthquakes. Conversion equations between magnitudes were constructed. P1.2-201 derived formulas and determined station magnitude corrections for local earthquake magnitude (ML and MLv).

Invited Talk I08-723 suggested considering the use of bulletins that present multiple hypotheses and probabilities. It was noted that the policy of flagging events should be based on realizing the relative costs of false positives and false negatives and basing the determination of thresholds on such analysis.

7.12. On-Site Inspection

Two of the Invited Talks dedicated to the 25th anniversary of the Treaty focused on the OSI component of the verification regime. OSI was also the subject of Topic 2.2 under Theme 2, Events and Nuclear Test Sites. Presentation I05-727 provided an overview of the remarkable development and interrelationship of OSI capabilities, particularly regarding the methodology for the planning and conduct of an inspection, the application of permitted inspection techniques and the training of inspectors. One key deliverable of work over the past 25 years is the first comprehensive draft list of equipment specifications for use during an OSI (Is5-239). The draft list was prepared in accordance with guidance provided by the OSI Task Leaders and Working Group B. Its content is based on extensive development and testing of equipment for all OSI techniques, with the exception of drilling. The list, which takes into account relevant Treaty provisions and the permitted inspection activities and techniques, is currently undergoing review by the States Signatories. P4.4-257 presented the different development phases of the OSI technology testing programme, from the definition of user requirements to functional design, prototyping and field testing, and also proposes new technical specifications for the equipment list.

Another key result of work in the past 25 years is the OSI training programme for inspectors, who are nominated by States Signatories. Thus far, three training cycles have been performed. The curriculum focused on new inspectors and included introductory and advanced blocks followed by a field exercise. The COVID-19 pandemic highlighted the need to use new training methods and reconsider certain aspects of the programme.

Infrastructure is a key enabler to conduct OSIs. Specifically, infrastructure is required to support the launch and conduct of an inspection within the strict OSI timelines and to ensure proper calibration, maintenance and protection of OSI equipment. Such infrastructure was put in place both at PTS headquarters in Vienna (OSI Operations Support Centre) and at the TeST Centre, which includes the Equipment Storage and Maintenance Facility for OSI equipment, in Seibersdorf, Austria. Another important aspect is field infrastructure, i.e. for sustainable operation of the base of operations, which has advanced in recent years. P2.2-220 explained the updated concept and organization of the OSI Operations Support Centre as an ad hoc part of the COPC. P2.2-575 addressed the certification, calibration, maintenance and protection of OSI equipment. To this end, a system has been developed to facilitate the management of OSI equipment at the TeST Centre, which serves headquarters requirements and is also designed for use during an OSI.

Several presentations covered OSI techniques and respective signatures. O2.1-420 described a new method to detect cavities from an underground nuclear explosion that uses the finite-interval spectral power of seismic ambient noise. O3.1-296 studied the potential of using time-lapse seismic surveying to identify ground zero by monitoring post-explosion dynamic phenomena. P2.2-619 presented a method to map radiation using multi-crystal spectrometers to improve spatial precision. P2.2-387 suggested the use of shielded HPGe detectors in field conditions. O2.2-029 and P2.2-030 presented a case study for use of the electrical resistivity tomography and combined ground magnetic and very low frequency electromagnetic geophysical techniques. P2.2-036 discussed the potential use of commercial ground penetrating radar (GPR) for OSI applications. P3.1-527 presented the results of extensive testing of a portable backpack system for the measurement and identification of radioactive material, based on an organic liquid scintillator with pulse shape discrimination for the simultaneous detection of gamma rays and neutrons. P2.2-704 used seismometers and vertical electrical sounding penetration tests to produce shear wave velocity maps that could be helpful in seismic micro-zonation.

P3.2-691 summarized the layout and design of the next-generation OSI field laboratory with regard to the specific requirements for measuring OSI-relevant xenon and argon isotopes. Improvements to field capable xenon detection systems for OSI were also reported (P3.2-424, P3.2-518). O3.2-654 presented challenges for the measurement of ^{37}Ar, which is one of the isotopes that can provide conclusive evidence of a nuclear test during an OSI. The measurement system uses liquefied argon as a liquid scintillator, thus overcoming limitations in sample size. The laboratory prototype has shown significant improvement in detection sensitivity. P2.1-474 discussed an evaluation of the viability of ^{39}Ar as a potential long term indicator with the possibility to detect subsurface concentrations even decades after an underground nuclear explosion.

Operation support technologies are critical for the success of an OSI. The integration of solar power into the OSI field power distribution (P2.2-230) was identified as an opportunity to enhance flexibility at the base of operations and to deployed field equipment. O2.2-108 addressed the topic of measures to ensure the robustness and availability of mission-critical software during an OSI. P3.1-302 proposed a four mode GNSS solution for OSI that is compatible with all existing navigation satellite systems and more reliable. P2.2-074 presented a study of a compact portable cognitive satellite system that could provide an option for OSI communication equipment development. O3.1-190 discussed the development of compact, high performance hardware for digital data evaluation methods that is especially useful in hand-held devices used for OSI due to their lower weight, power supply and cost. P2.2-348 focused on the application of a 3-D visualization platform as a tool to support and enhance OSI operation management and decision making. P2.2-027 presented the use of radio frequency identification (RFID) to address the security and tamper-proofing of environmental sampling for OSI.

The application of microsatellites featured in P3.3-059 and P3.3-692, which described their possible use to determine tectonic events. O2.2-199 addressed the potential of UAVs in the context of OSI. Based on the example of geomagnetic field mapping, the presentation examined the technical capability of UAV platforms and also considered their use with respect to Treaty provisions. P3.1-495 proposed the use of a wide spectral imaging spectrometer mounted on aviation platforms. Several application fields using hyperspectral data were analysed. O3.3-295 focused on a platform for a magnetic sensor, while P3.3-110, more generically, described a cost-efficient application for OSI that includes UAVs as a platform to carry multispectral sensors. P2.2-568 presented the status of the airborne simulator to support the development and testing of airborne OSI equipment.

On the processing of imagery, presentations discussed a range of different sensors, both optical and radar. O3.3-117 focused on a processing tool that could be incorporated during the launch phase of an OSI and highlight areas that warrant the attention of the inspection team. O3.3-085 described the application of a semi-automated pixel–object fusion algorithm, and P3.3-586 used a pixel subtraction method for event verification. P3.3-132 described the use of differential interferometry synthetic aperture radar for the identification of land deformation. However, these methods rely on the availability of relevant imagery acquired before and after the triggering event. P3.6-439 carried out a preliminary study of the application of artificial intelligence and machine learning vision technology to assist OSI operations. P3.6-096 described a system solution to support the management of the living and working areas of the OSI inspection team and inspected State Party, based on AI-related and deep learning.

The potential for OSI technical developments and innovations was highlighted in I05-727. These included:

- Development of remaining techniques (e.g. resonance seismometry, active seismic surveys and drilling) and finalizing the development cycle of existing techniques;
- Development of equipment that increases efficiency and efficacy of conducting OSIs;
- Development of capabilities for OSIs in other than standard environmental conditions;
- Development of capabilities for OSIs in environments other than underground.

7.13. Civil and Scientific Applications

Invited Talk I06-721, on civil and scientific applications of CTBT technologies, was presented by the Director of the IDC Division, who emphasized that the primary purpose of the verification regime is to confirm compliance with the Treaty. However, the Treaty explicitly states that the States Parties may benefit from using IMS data, which are a tremendous asset, for peaceful and scientific purposes. The Preparatory Commission has defined the rules and procedures for data sharing. The main category of those who have access to IMS data is authorized users, comprising those designated by States Signatories to use IMS data and IDC products for nuclear explosion monitoring. In addition, the Preparatory Commission has decided to provide data for two specific civil applications: tsunami warning and radiological and nuclear emergencies. Scientific applications follow the decision of the CTBTO Preparatory Commission in November 2000, which states that the PTS may provide IMS data and IDC products to organizations for the purpose of conducting research associated with the development of the IMS and the IDC. Since 2011, the virtual Data Exploitation Centre (vDEC) has allowed scientists and researchers access to IMS data.

Scientific and civil applications were discussed in panels J06 and J09, as well as Invited Talks I06-719 and I09-742. Many oral and poster presentations, specifically under Topic 5.2, were devoted to possible additional contributions to issues of global concern such as disaster risk mitigation, climate change studies and the United Nations Sustainable Development Goals. Monitoring and understanding volcanic eruptions and earthquakes were dealt with extensively in presentations under Topics 1.1, 1.2, 1.3, 2.3 and 5.2.

A strong relationship between the scientific and technological community and the CTBTO is a way to ensure that the IMS remains at the forefront of technological innovation and that no nuclear explosion will go undetected (J04). A striking example is related to the announced nuclear tests by the Democratic People's Republic of Korea. Scientists are studying the characteristics of the depths of the source in order to improve Treaty monitoring methods based on moment tensor analysis or cross-correlation.

There is definitely potential for more civil applications of IMS data beyond tsunami early warning and international cooperation in the event of nuclear and radiological emergencies. For example, the monitoring of recent volcanic eruptions was discussed in

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

P1.1-133, P1.1-588, O1.1-457, P2.3-708, P1.1-253 and P5.2-395. Research progress demonstrates the important role of the IMS network and how it can be enriched by well-designed and optimized regional infrasound networks (P1.1-264) in order to notify civil society and mitigate volcanic hazards (O1.1-536 and P1.1-133). Considering the potential of multidisciplinary approaches is essential (I07-529).

Appendix 1
Conference Programme

Appendix 1: SnT2021 Conference Programme

MONDAY, 28 JUNE 2021 Hybrid Format Festsaal, Hofburg Palace, Vienna/Online	
10:00-12:30	**High Level Opening: Session 1**
	SnT21@25th Anniversary of the CTBT: Ceremonial Opening and Political Remarks (G1) Link, *Video 1/4, 00:08:50* Musical Interlude Facilitated Dialogue on CTBT@25years: Evolution of the CTBT, the Organization and Its Technologies and CTBT's Model Function of Inclusion and Science Cooperation (G2) Link, *Video 1/4, 01:42:00*
13:00-13:45	**CTBTO Youth Group Event**
	Evolution of the SnT Conference: CTBTO Youth Group Dialogue with Executive Secretary Lassina Zerbo (SE1) Link, *Video 2/4*
14:00-16:30	**High Level Opening: Session 2**
	Keynote Address. Artificial Intelligence: What, Why and How It Could Transform Our Missions (G3) Link, *Video 3/4, 05:20:00* Musical Interlude Keynote Address on Space Science and Technology for Global Sustainable Development, Peace and Security Link, *Video 3/4, 00:58:45* Panel Discussion: Space Science and Technology for Global Sustainable Development, Peace and Security (G4) Link, *Video 3/4, 01:11:30* Musical Interlude Remarks by Executive Secretary Lassina Zerbo Link, *Video 4/4, 00:00:25*
16:45-17:45	**European Union–CTBTO Panel Discussion**
	Securing a Nuclear Test Free World for Youth and the Next Generations (G5) Link, *Video 4/4, 00:09:20*

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

<table>
<tr><th colspan="4">TUESDAY, 29 JUNE 2021
Virtual Format</th></tr>
<tr><td>9:00-12:00</td><td colspan="3">E-Poster Sessions</td></tr>
<tr><td></td><td colspan="3">T1.1. The Atmosphere and Its Dynamics
T1.2. The Solid Earth and Its Structure
T1.3. The Oceans and Their Properties
T5.3. Capacity Building, Education, Communication and Public Awareness</td></tr>
<tr><td>9:00-19:15</td><td colspan="3">E-Poster Round Tables, Oral Sessions, Talks, Panel Discussions and Events</td></tr>
<tr><td></td><td>Stage 1</td><td>Stage 2</td><td>Stage 3</td></tr>
<tr><td></td>
<td>9:00-10:00 E-Poster Round Table T1.3
Link, Video 1/22, 00:04:00

9:00-10:00 E-Poster Round Table T1.1
Link, Video 1/22, 00:23:00

10:00-11:00 E-Poster Round Table T1.2
Link, Video 2/22, 00:00:25

10:00-11:00 E-Poster Round Table T5.3
Link, Video 2/22, 00:25:00

11:00-11:30 Special Talk
25 Years of the CTBT Seismic Technology: New Applications at the IDC for SHI Expert Technical Analysis (Is1-353)
Link, Video 2/22, 00:57:17

11:30-13:00 Panel Discussion
Lessons from Historic Nuclear Test Explosions and Value of Recorded Signals for Monitoring Science (J03)
Link, Video 2/22, 01:28:00</td>
<td>13:30-15:30 Oral Session
T2.4. Atmospheric and Subsurface Radionuclide Background and Dispersion
Link, Video 1/18

15:45-17:30 Oral Session
T1.2. The Solid Earth and Its Structure
Link, Video 2/18

17:30-18:30 Oral Session
T2.5. Historical Data from Nuclear Test Monitoring
Link, Video 3/18

18:30-19:00 Special Talk
25 Years of the CTBT
Review and Outlook of Radionuclide Screening Methods for Discriminating Nuclear Explosion Signals from Normal Radioactivity Background in the Atmosphere (Is7-604)
Link, Video 4/18</td>
<td>11:30-12:30 Event 1
Resilience of the CTBT Monitoring Regime, Including Lessons Learned from the COVID-19 Pandemic Crisis (M1)
Link, Video 1/14

13:30-15:15 Oral Session
T5.3. Capacity Building, Education, Communication and Public Awareness
Link, Video 2/14

15:45-17:15 Oral Session
T3.6. Artificial Intelligence and Machine Learning
Link, Video 3/14

17:15-18:15 Event 2
Resilience of the CTBT Monitoring Regime, Including Lessons Learned from the COVID-19 Pandemic Crisis (M2)
Link, Video 4/14</td></tr>
</table>

TUESDAY, 29 JUNE 2021 Virtual Format			
	Stage 1	Stage 2	Stage 3
	13:30-14:30 Highlight Talk on the Solid Earth and Its Structure Imaging the Earth's Deep Interior Using Seismic Waves (H1-720) Link, *Video 3/22, 00:00:00* **14:30-15:30** Invited Talk 25 Years of the CTBT Challenges and Achievements of Monitoring for Nuclear Test Explosions in the Context of the CTBT (I01-722) Link, *Video 3/22, 01:00:00* **15:45-16:45** Invited Talk 25 Years of the CTBT The IMS Radionuclide Network: A Unique Machine Not Yet Fully Exploited (I04-717) Link, *Video 4/22, 00:01:35* **16:45-17:15** Special Talk 25 Years of the CTBT Advancements in Atmospheric Transport Modelling at the CTBTO PTS During the Past Two Decades and Plans for the Future (Is4-322) Link, *Video 4/22, 00:58:46* **17:15-18:45** Panel Discussion Innovation Affecting CTBT: International Monitoring System (IMS Sensors) (J04) Link, *Video 5/22*		**18:15-19:15** CTBTO Youth Group Fireside Chat 1 (SE8) Link, *Video 5/14*

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

WEDNESDAY, 30 JUNE 2021 Virtual Format			
9:00-12:00	**E-Poster Sessions**		
	T2.1. Characterization of Treaty-Relevant Events T2.2. Challenges of On-Site Inspection T2.3. Seismoacoustic Sources in Theory and Practice T2.4. Atmospheric and Subsurface Radionuclide Background and Dispersion T2.5. Historical Data from Nuclear Test Monitoring		
9:00-19:15	**E-Poster Round Tables, Oral Sessions, Talks, Panel Discussions and Events**		
	Stage 1	**Stage 2**	**Stage 3**
	9:00-10:00 E-Poster Round Table T2.1 Link, *Video 6/22, 00:00:00* **9:00-10:00** E-Poster Round Table T2.5 Link, *Video 6/22, 00:18:05* **10:00-11:00** E-Poster Round Table T2.2 Link, *Video 7/22, 00:00:00* **10:00-11:00** E-Poster Round Table T2.3 Link, *Video 7/22, 00:15:45* **11:00-12:15** Oral Session T4.5. Resilience of the CTBT Monitoring Regime, Including Lessons Learned from the COVID-19 Pandemic Link, *Video 8/22*	**9:30-10:30** E-Poster Round Table T2.4 Link, *Video 5/18* **11:00-12:45** Oral Session T3.5. Data Analysis Algorithms Link, *Video 6/18, Radionuclide 00:00:00, SHI 00:56:00* **13:30-14:45** Oral Session T2.2. Challenges of On-Site Inspection Link, *Video 7/18*	**11:30-12:30** Invited Talk: 25 Years of the CTBT The CTBT Hydroacoustic Network at 25 Years (I02-718) Link, *Video 6/14* **13:30-14:30** CTBTO Youth Group Educational Initiative for Young Professionals with Technical Background International Gender Champions and Youth: Collaboration for Successful Outcomes (SE4) Link, *Video 7/14* **14:30-16:15** Oral Session T3.1. Design of Sensor Systems and Advanced Sensor Technologies Link, *Video 8/14*

WEDNESDAY, 30 JUNE 2021 Virtual Format			
	Stage 1	**Stage 2**	**Stage 3**
	13:15-14:15 Panel Discussion Lessons Learned from the COVID-19 Pandemic Crisis as a Resilience Test of the CTBT Monitoring Regime (J02) Link, *Video 9/22* **14:15-14:45** Special Talk 25 Years of the CTBT Data Analysis: Machine Learning Prospects for Automatic SHI Processing (Is6-454) Link, *Video 10/22, 00:00:00* **14:45-16:15** Panel Discussion Innovation Affecting CTBT: IDC Data Analysis (Needs, Ideas and Implementation Pathways) (J05) Link, *Video 10/22, 00:28:00* **16:30-17:00** Special Talk 25 Years of the CTBT Advancements in Hydroacoustic Signal Processing at CTBT IDC During the Past Two Decades and Plans in the Future (Is2-283) Link, *Video 11/22, 00:00:00* **17:00-18:00** Highlight Talk on the Oceans and Their Properties Improving Ocean Monitoring Through the Expansion of the Global Seismographic Network on the Seafloor (H2-716) Link, *Video 11/22, 00:33:00*	**14:45-16:15** Oral Session T4.1. Performance Evaluation and Modelling of the Full Verification System and Its Components Link, *Video 8/18* **16:30-19:15** Oral Session T1.1. The Atmosphere and Its Dynamics Link, *Video 9/18*	**16:30-17:00** Oral Session T5.2. Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals Link, *Video 9/14, 00:10:50* **18:00-19:15** CTBTO Youth Group Mentoring Session with Group of Eminent Persons (SE2)

<table>
<tr><th colspan="4">THURSDAY, 1 JULY 2021
Virtual Format</th></tr>
<tr><td>9:00-12:00</td><td colspan="3">E-Poster Sessions</td></tr>
<tr><td></td><td colspan="3">T3.1. Design of Sensor Systems and Advanced Sensor Technologies
T3.2. Laboratories Including Transportable and Field Based Facilities
T3.3. Remote Sensing, Imagery and Data Acquisition Platforms
T3.5. Data Analysis Algorithms
T3.6. Artificial Intelligence and Machine Learning
T5.2. Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals</td></tr>
<tr><td>9:00-19:00</td><td colspan="3">E-Poster Round Tables, Oral Sessions, Talks, Panel Discussions and Events</td></tr>
<tr><td></td><td>Stage 1</td><td>Stage 2</td><td>Stage 3</td></tr>
<tr><td></td>
<td>9:00-10:00 E-Poster Round Table T3.1
Link, Video 12/22

10:00-11:00 E-Poster Round Table T3.2
Link, Video 13/22

10:00-11:00 E-Poster Round Table T3.3
Link, Video 13/22

10:00-11:00 E-Poster Round Table T3.5
Link, Video 13/22

10:00-11:00 E-Poster Round Table T3.6
Link, Video 13/22

11:00-12:30 Panel Discussion Regional Data for Treaty Monitoring (J07)
Link, Video 14/22</td>
<td>10:00-11:00 E-Poster Round Table T5.2
Link, Video 10/18

11:30-12:30 Oral Session T2.3. Seismoacoustic Sources in Theory and Practice
Link, Video 11/18

13:30-15:45 Oral Session T2.1. Characterization of Treaty-Relevant Events
Link, Video 12/18; segment on Beirut explosion begins at 01:11:00

16:15-17:15 Oral Session T3.2. Laboratories Including Transportable and Field Based Facilities
Link, Video 13/18</td>
<td>13:30-14:30 Oral Session T4.3. Information Technology, Power Systems and Other Enabling Technologies
Link, Video 10/14

14:30-15:45 Oral Session T4.4. Network Sustainability and Systems Engineering for CTBT Verification
Link, Video 11/14

16:15-17:45 Oral Session T1.3. The Oceans and Their Properties
Link, Video 12/14

17:45-19:00 Oral Session T3.3. Remote Sensing, Imagery and Data Acquisition Platforms
Link, Video 13/14</td></tr>
</table>

THURSDAY, 1 JULY 2021 Virtual Format			
	Stage 1	**Stage 2**	**Stage 3**
	13:30-14:30 Highlight Talk on the Atmosphere and Its Dynamics Progress and Challenges in Atmospheric Sciences (H3-715) Link, *Video 15/22* **14:30-15:30** Invited Talk 25 Years of the CTBT Status of Preparations for the Support of On-Site Inspections (I05-727) Link, *Video 16/22, 00:00:00* **15:30-16:00** Special Talk 25 Years of the CTBT Development of the First Comprehensive Draft List of Equipment for Use During OSIs (Is5-239) Link, *Video 16/22, 00:59:00* **16:15-17:15** Invited Talk 25 Years of the CTBT 25 Years of Infrasound Monitoring: Achievements and New Challenges (I03-714) Link, *Video 17/22, 00:00:00*	**17:15-17:35** Preceding Talk to Panel Discussion on Human Versus Machine Knowledge Versus Data (I08-723) Link, *Video 14/18* **17:35-19:00** Panel Discussion Human Versus Machine (J08) Link, *Video 14/18*	

THURSDAY, 1 JULY 2021 Virtual Format			
	Stage 1	**Stage 2**	**Stage 3**
	17:15-17:45 Special Talk 25 Years of the CTBT Infrasound Processing System at the IDC: From Rudimentary to Maturity (Is3-381) *Link, Video 17/22, 00:00:00* **17:45-18:45** CTBTO Youth Group Fireside Chat 2 (SE9) *Link, Video 17/22, 01:31:00*		

FRIDAY, 2 JULY 2021 Virtual Format			
9:00-12:00	**E-Poster Sessions**		
	T4.1. Performance Evaluation and Modelling of the Full Verification System and Its Components T4.3. Information Technology, Power Systems and Other Enabling Technologies T4.4. Network Sustainability and Systems Engineering for CTBT Verification T4.5. Resilience of the CTBT Monitoring Regime, Including Lessons Learned from the COVID-19 Pandemic T5.1. Science in Policy Discussions and Scientific Lessons Learned from Other Arms Control Agreements and Arrangements		
9:00-18:00	**E-Poster Round Tables, Oral Sessions, Talks, Panel Discussions and Events**		
	Stage 1	**Stage 2**	**Stage 3**
	10:30-11:00 Invited Talk Risk Mitigation Use of Infrasound Data for Early Notification of Volcanic Ash Advisory Centres (I07-529) Link, *Video 18/22* **11:00-11:20** Preceding Talk to Panel Discussion on Synergy Among Monitoring Systems to Address Hazard Mitigation and Global Challenges Welcome to Risk: As We Know It, or Do We? (I09-742) *Link, Video 19/22, 00:00:00* **11:20-12:30** Panel Discussion Synergy Among Monitoring Systems to Address Hazard Mitigation and Global Challenges (J09) *Link, Video 19/22, 00:23:15*	**9:00-10:00** E-Poster Round Table 4.1 *Link, Video 15/18, 00:00:00* **9:00-10:00** E-Poster Round Table 4.3 *Link, Video 15/18, 00:29:30* **9:00-10:00** E-Poster Round Table 4.4 *Link, Video 15/18, 00:38:10* **10:00-11:00** E-Poster Round Table 4.5 *Link, Video 16/18, 00:00:00* **10:00-10:30** E-Poster Round Table 5.1 *Link, Video 16/18, 00:22:15*	**11:30-12:30** Panel Discussion Communicating Uncertainty Among Scientists to Policy Makers and the Public (J11) *Link, Video 14/14*

FRIDAY, 2 JULY 2021 Virtual Format			
	Stage 1	**Stage 2**	**Stage 3**
	13:30-13:50 Invited Talk Civil and Scientific Applications Sustainable Development, Disaster Risk Reduction and CTBTO Verification Regime (I06-719) Link, *Video 20/22, 00:00:00* **13:50-14:15** Invited Talk Civil and Scientific Applications Civil and Scientific Applications of IMS Data (I06-721) Link, *Video 20/22, 00:26:50* **14:15-15:15** Panel Discussion Civil and Scientific Applications: Prospects (J06) Link, *Video 20/22, 00:43:25*	**11:30-12:00** Special Talk The "Anthropocene Epoch", in memory of Paul Crutzen (1933-2021) Multiple Reasons for the Anthropocene: Paul Crutzen's Contribution to Save Planetary Boundaries (I10-749) Link, *Video 17/18, 00:00:00* **12:00-12:30** Special Talk The "Anthropocene Epoch", in memory of Paul Crutzen (1933-2021) Artificial Radionuclide Fallout: A Marker for the Start of the Anthropocene Epoch (I10-752) Link, *Video 17/18, 00:34:00* **13:30-13:45** Side Event OSI Educational Initiative for Young Professionals with a Technical Background (SE3) Link, *Video 18/18*	
15:30-16:00	**Closing Session**		
	Slide presentation and musical interlude Remarks from the SnT2021 Programme Coordinator Link, *Video 21/22, 00:03:10* Awards ceremony Link, *Video 21/22, 00:11:20*		

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

FRIDAY, 2 JULY 2021 Virtual Format			
	Closing remarks by Executive Secretary Lassina Zerbo *Link, Video 21/22, 00:17:20*		
16:00-18:00	**National Data Centre Session**		
	Stage 1	**Stage 2**	**Stage 3**
	16:00-18:00 National Data Centre Session (SE5) *Link, Video 22/22*		

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Appendix 2
Statistics

Appendix 2: Statistics

All statistical information on the CTBT: Science and Technology 2021 (SnT2021) conference refers to actual presentations given during in the conference. Submitted abstracts for which no presentations were given or for which no files were uploaded are not included in the tables below.

Conference Participants

Number of Participants

The number of participants in SnT conferences has steadily increased, with 1659 participants in 2021. A total of 1546 attendees registered for the full SnT2021 week. Table 2.1 provides an overview of the number of participants and gender distribution since SnT2015.

Table 2.1. Participation in Science and Technology Conferences (2015, 2017, 2019, 2021)

Year	Men	Women	Mx	Total
SnT2015	518	182		700
SnT2017	621	279		900
SnT2019	617	583		1200
SnT2021	1119	527	13	1659

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Regional Distribution of Participants

Table 2.2 presents an overview of the regional distribution of participants at SnT2021.

Table 2.2. Regional Distribution of Participants at SnT2019 and SnT2021

Region	2019 Share (%)	2021 Share (%)
Africa	6.6	16.5
Eastern Europe	8.4	9.3
Latin America and the Caribbean	3.5	7.8
Middle East and South Asia	5.7	12.4
North America and Western Europe	57.1	41.0
South East Asia, the Pacific and the Far East	5.6	10.4
International Organizations	13.0	2.5

Panel Discussions

Panel discussions are one of the most interesting ways to exchange knowledge and encourage lively debate. The CTBT: Science and Technology conference series has always served as a platform for people from all over the world to share new findings and converse about future developments. At SnT2021, most panels were devoted to long view discussions related to the 25th anniversary of the Treaty. The total number of panels was reduced compared with 2019 to allow more time for Invited Talks related to these discussions. Table 2.3 presents an overview of panel discussions at SnT2015, SnT2017, SnT2019 and SnT2021.

Table 2.3. Number of Panel Discussions at SnT Conferences (2015, 2017, 2019, 2021)

Year	Number of Panel Discussions
SnT2015	7
SnT2017	9
SnT2019	19
SnT2021	11

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Distribution of Panellists by Geographical Region and Gender

The panellists at SnT2021 were geographically diverse, reflecting the diversity of the participants in the conference (although there was a somewhat larger portion from North America and Western Europe). Table 2.4 shows the distribution of panellists according to geographical region and gender.

Table 2.4. Distribution of SnT2021 Panellists by Geographical Region and Gender

Region	Women	Men	Total	Share 2019 (%)	Share 2021 (%)
Africa	1	7	8	9	13.6
Eastern Europe	1	2	3	7	5.1
Latin America and the Caribbean	2	5	7	11	11.9
Middle East and South Asia	1	0	1	5	1.7
North America and Western Europe	5	25	30	44	50.8
South East Asia, the Pacific and the Far East	2	8	10	11	16.7
International Organizations				12	
Total	12	47	59	100	100

Oral Presentations

At the heart of this prestigious event were the individual presentations under each of the themes. In SnT2021, a category of longer Invited Talks was added, which resulted in a slight decrease of the total number of talks. Table 2.5 presents an overview of the number of oral presentations at SnT2015, SnT2017, SnT2019 and SnT2021.

Table 2.5. Number of Oral Presentations at SnT Conferences (2015, 2017, 2019, 2021)

Year	Oral Presentations
SnT2015	80
SnT2017	100
SnT2019	118
SnT2021	108

Distribution of Oral Presenters by Geographical Region and Gender

Table 2.6. Distribution of SnT2021 Oral Presenters by Geographical Region and Gender*

Region	Women	Men	Total	(%) Share
Africa	0	4	4	3.7
Eastern Europe	2	4	6	5.5
Latin America and the Caribbean	0	2	2	1.8
Middle East and South Asia	6	4	10	9.3
North America and Western Europe	14	54	68	63.0
South East Asia, the Pacific and the Far East	0	5	5	4.6
International Organizations	2	11	13	12.0
Total	24	84	108	100

* This figure includes oral presentations under Special Talks on the 25th anniversary of the CTBT, Invited Talks preceding Panel Discussions, and Oral Presentations under Themes and Topics.

Poster Presentations

In SnT2021, posters were presented by uploading slide files and short, two minute videos. Posters could be viewed anytime before, during or after the conference. In addition, poster presenters could choose to participate in one of the ten round table sessions, where they could briefly summarize and discuss the highlights of their posters. Table 2.7 presents an overview of the number of poster presentations at SnT2015, SnT2017, SnT2019 and SnT2021.

Table 2.7. Number of Poster Presentations at SnT Conferences (2015, 2017, 2019, 2021)

Year	Poster Presentations
SnT2015	320
SnT2017	340
SnT2019	342
SnT2021	365

Distribution of Poster Presenters by Geographical Region

Table 2.8. Distribution of SnT2021 Poster Presenters by Geographical Region

Region	Total	(%) Share
Africa	30	8.2
Eastern Europe	29	7.9
Latin America and the Caribbean	27	7.4
Middle East and South Asia	32	8.8
North America and Western Europe	143	39.2
South East Asia, the Pacific and the Far East	38	10.4
International Organizations	66	18.1
Total	365	100

Themes and Topics

Table 2.9 presents an overview of SnT2021 oral and poster presentations according to theme and topic.

Table 2.9. SnT2021 Presentations According to Theme and Topic

Theme and Topic	Oral Presentations	Poster Presentations
Theme 1. The Earth as a Complex System	16	61
T1.1 The Atmosphere and Its Dynamics	6	24
T1.2 The Solid Earth and Its Structure	5	24
T1.3 The Oceans and Their Properties	5	13
Theme 2. Events and Nuclear Test Sites	24	95
T2.1 Characterization of Treaty-Relevant Events	8	13
T2.2 Challenges of On-Site Inspection	3	13
T2.3 Seismoacoustic Sources in Theory and Practice	3	24
T2.4 Atmospheric and Subsurface Radionuclide Background and Dispersion	7	34
T2.5 Historical Data from Nuclear Test Monitoring	3	11

Table 2.9. SnT2021 Presentations According to Theme and Topic (cont.)

Theme and Topic	Oral Presentations	Poster Presentations
Theme 3. Verification Technologies and Technique Application	24	105
T3.1 Design of Sensor Systems and Advanced Sensor Technologies	6	39
T3.2 Laboratories Including Mobile and Field Based Facilities	3	4
T3.3 Remote Sensing, Satellite Imagery and Data Acquisition Platforms	4	9
T3.5 Data Analysis Algorithms	6	33
T3.6 Artificial Intelligence and Machine Learning	5	20
Theme 4. Performance Evaluation and Optimization	15	62
T4.1 Performance Evaluation and Modelling of the Full Verification System and Its Components	5	15
T4.3 Information Technology, Power Systems and Other Enabling Technologies	3	15
T4.4 Network Sustainability	3	10
T4.5 Resilience of the CTBT Monitoring Regime, Including Lessons Learned from the COVID-19 Pandemic	4	22
Theme 5. CTBT in a Global Context	10	42
T5.1 Science in Policy Discussions and Lessons Learned from Other Arms Control Agreements and Arrangements	0	7
T5.2 Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals	4	16
T5.3 Capacity Building, Education, Communication and Public Awareness	6	19
Total	89	365

SnT2021: A Hybrid Virtual Conference
Opening Day at the Hofburg Palace, Vienna
25th Anniversary of the Comprehensive Nuclear-Test-Ban Treaty: Invited Talks
Highlight Talks
Panel Discussions
Oral and Poster Presentations
Relevance to CTBTO Activities and Verification Science
Appendix 1. SnT2021 Conference Programme
Appendix 2. SnT2021 Conference Statistics
EXECUTIVE SUMMARY
AR CN EN FR RU SP

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE