SnT 2023
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

CTBTO
PREPARATORY COMMISSION

Science and Technology 2023 Conference
Scientific Advances in CTBT Monitoring and Verification

Review of Presentations and Outcomes of the Comprehensive Nuclear-Test-Ban Treaty:
Science and Technology 2023 Conference

Hofburg Palace
Vienna, Austria
19 to 23 June 2023

Executive Summary

The CTBT: Science and Technology 2023 conference (SnT2023) was held in the Hofburg Palace in Vienna, Austria, and online from 19 to 23 June 2023. This report provides an overview of the scientific and technological contributions presented at the conference and identifies some highlights and potential focus areas for the future.

SnT2023 is the seventh meeting of the CTBT: Science and Technology conference series which is the flagship event to address the dependence of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) on innovation in order to continuously enhance the capabilities of the verification regime of the Treaty as well as to help move the Treaty closer to universalization and entry into force. Its four main objectives were:

- To identify advances in technology and methods for improving nuclear-test-ban monitoring and on-site inspection (OSI).
- To demonstrate how scientific developments and cooperation can support national needs, frame policy objectives in support of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) and promote its universalization.
- To broaden, connect and strengthen the scientific communities working in nuclear-test-ban monitoring and OSI, including young scientists, and to enhance the geographical and gender representations of these communities.
- To promote civil and scientific applications, capacity building and training related to CTBT techniques and data.

At SnT2023, over 2000 participants from 148 countries registered, with 80 per cent indicating in-person attendance and almost 450 participants made use of the online access. A large number of participants and inclusiveness demonstrated "The Power of Together", which emerged as an overarching motto expressed by Executive Secretary Robert Floyd on the opening day. The event brought together scientists, technologists, academics and students. In addition, diplomats and representatives from the Permanent Missions, government officials and participants from the scientific advisory, media and advocacy spheres attended the conference.

Although SnT2023 was optimized for on-site experience at the Hofburg Palace, it featured virtual components for active online participation to support broader outreach and global inclusiveness. This hybrid format was applied for the first time to most of the event.

The previous conference, SnT2021, had to be conducted largely online owing to the COVID-19 pandemic. SnT2023 built on the successful experience gained in 2021. The SnT2023 Event Platform was available with almost identical content on the web platform and on the mobile app used by more than 1400 participants. A lounge area in the Hofburg Palace facilitated on-site participants to join online meetings where e-posters were presented on touch screens and made accessible online via the SnT2023 Event Platform. The opportunity of presenting an e-poster remotely, resulted in around 100 more presentations being given compared to previous SnT conferences with five times fewer withdrawals than in SnT2019, which was the last conference without online presentation opportunities.

On 19 June, the Executive Secretary opened the conference alongside a diverse group of high level speakers at ministerial, agency head, senior official and expert levels. This high level segment provided a political and diplomatic context to the conference. Key themes of that segment, which permeated the entire conference, were inclusion, unity, universalization and harnessing the benefits of the CTBT science and technologies for all. This was followed by two high level panels, one in French and the other jointly organized with

the European Union Delegation. For all these high level elements, interpretation in the six languages of the Commission was available to in-person participants. On Monday evening, three panels were held in parallel in languages of the Commission (Arabic, French and Spanish) with a focus on regional benefits and cooperation between CTBT States Signatories.

The dense programme during the remainder of the week was structured around several parallel sessions in the afternoons, while mornings were dedicated to e-poster elements, side events or a workshop. The programme contained eight invited talks, a highlight talk, ten panel discussions, eight side events, one workshop spanning two consecutive mornings and 24 scientific topics distributed amongst the five themes of the conference.

1. The Earth as a Complex System
2. Events and Nuclear Test Sites
3. Monitoring and On-Site Inspection Technologies and Techniques
4. Sustainment of Networks, Performance Evaluation and Optimization
5. CTBT in a Global Context

A total of 869 abstracts were submitted and reviewed and more than 700 were eventually accepted. At the conference, there were 101 oral presentations and 455 e-poster presentations of which over 400 were introduced by a lightning talk. Building on past practice, participants were invited to vote via the dedicated mobile app. The SnT2023 participants cast over 1000 votes - an unprecedented number for an SnT conference - which led to six awards being presented on the final day of the conference: the European Union Star award, an Early Career Scientist award, the award for the best oral presentation and, for the first time, three awards for the best e-posters in recognition of the large number of e-posters and their high quality.

Special highlights across all programme components included the in-depth analysis and review of the global impact of the Hunga Tonga-Hunga Ha'apai volcano eruption on 15 January 2022, the development of new primary measurement standards for traceable calibration of infrasound and low frequency seismic measurements, the achievements and challenges of noble gas monitoring, the sustainment of the International Monitoring System (IMS) and the preparations for the 2025 Integrated Field Exercise that will take place in Sri Lanka. Special emphasis was put on the benefits that all CTBT States Signatories gain from the access to data of the IMS for Treaty verification and for civil and scientific applications. Emphasis was also placed on the advantages arising from related capacity building and training of those who contribute to the installation and maintenance of relevant monitoring facilities, and to the processing and analysis of the IMS data. Several panel discussions were jointly organized with cooperating partners, namely the European Union Delegation, the United Nations Office for Disarmament Affairs, and Le Cercle Vienne. More than a dozen professional societies presented the status of their cooperation with the CTBTO and how they provide support for the CTBT.

Importance was given to fully integrate early career scientists, including the CTBTO Youth Group and the Young Professional Network, for example as panellists and members of the Scientific Programme Committee. In order to enhance geographic distribution, travel support was provided and remote e-poster presentation was offered. The share of female participants (35% compared to 32% at SnT2021) and female oral speakers (31% compared to 22% at SnT2021) increased compared with previous SnT conferences and gender parity was achieved amongst invited speakers and panellists. Further measures for inclusiveness include the availability of a prayer room and a nursing mother's room as well as the implementation of a comprehensive disability inclusion concept.

SnT2023 additionally featured an exhibition area with 25 booths from external vendors and organizations and eight PTS booths and exhibits. Three tours were organized to visit the CTBTO Operations Centre in the Vienna International Centre. Eight companies, the European Union Delegation and the Norwegian Seismic Array sponsored catering events. Besides outreach through social media, 11 journalists were sponsored to attend the conference. The journalists answered a call for applications and were selected based on their publication concept with special emphasis on non-ratifying Annex 2 States.

The structure of the SnT2023 report is as follows:

1. Introduction
2. High Level Opening
3. Panel Discussions and Invited Talks
4. Oral and E-Poster Presentations
5. Closing and Awards
6. Relevance to CTBTO Activities and Verification Science

Appendix 1: Scientific Programme Committee

Appendix 2: Side Events (SE) and Workshop (WS)

Appendix 3: Exhibitors and Sponsors

Appendix 4: Statistics

Overall, the conference provided a forum for the Commission to maintain awareness of emerging technologies relevant to CTBT monitoring, OSI preparedness and related areas. The information of most relevance to CTBTO activities and verification science is summarized in Chapter 6 under:

1. Measurement Technologies
2. Earth Characterization and Propagation of Signals
3. Processing of Data
4. Historical Data and Events
5. Event Physics and Screening Methods
6. CTBT in the Broader Context.

All conference materials including the SnT2023 Conference Programme, Book of Abstracts, presentation files, and participants list can be found on the SnT2023 page on the CTBTO conference portal. Selected papers will be published in a topical volume of *Pure and Applied Geophysics* with the title "Nuclear Explosion Monitoring and Verification: Science and Technology to Tackle Global Challenges". The session videos are available on the CTBTO YouTube Channel and photos can be found on the SnT2023 album on Flickr.

Abbreviations

AS	auxiliary seismic (station)
ATM	atmospheric transport modelling
CTBT	Comprehensive Nuclear-Test-Ban Treaty
CTBTO	Comprehensive Nuclear-Test-Ban Treaty Organization
CYG	CTBTO Youth Group
GIMO	Geospatial Information Management for OSI
GPU	graphics processing unit
HA	hydroacoustic (station)
IASPEI	International Association of Seismology and Physics of the Earth's Interior
IDC	International Data Centre
IEEE	Institute of Electrical and Electronic Engineers
IMS	International Monitoring System
IS	infrasound (station)
ISC	International Seismological Centre
IT	information technology
ITF	inspection team functionality
NDC	National Data Centre
OSI	on-site inspection
PS	primary seismic (station)
PTS	Provisional Technical Secretariat
RASA	Radionuclide Aerosol Sampler Analyzer
REB	Reviewed Event Bulletin
RL	radionuclide (laboratory)
RN	radionuclide (station)
RSTT	regional seismic travel time
SAUNA	Swedish Automatic Unit for Noble Gas Acquisition
SDG	United Nations Sustainable Development Goals
SI	International System of Units
SnT	CTBT: Science and Technology conference
SPALAX	Système de prélèvement automatique en ligne avec l'analyse des radio xénons
SPC	Scientific Programme Committee
STAX	Source Term Analysis of Xenon
STEM	science, technology, engineering and mathematics
vDEC	virtual Data Exploitation Centre
VSAT	very small aperture terminal
WGB	Working Group B

Contents

1. Introduction

1. Introduction

1.1. Purpose of This Report

The CTBT: Science and Technology 2023 conference (SnT2023) took place in the historic Hofburg Palace in Vienna, Austria, and online from 19-23 June 2023. It brought together over 2000 scientists, technologists, academics, researchers, journalists, young professionals, youth advocates and State Signatory and civil society representatives from around the world. SnT2023 was the first fully in-person gathering since 2019. Owing to advances made in hybrid meeting technology since the COVID-19 pandemic, the week-long event was also fully accessible to online attendees.

This report contributes to the written archive of progress made in Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification science and technology presented as part of the Science and Technology (SnT) process. As such, its intended audience comprises the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) as well as all those who are active in CTBT-relevant fields or who may be contemplating research and development related to the CTBT. This report is also of interest to policymakers and others who are not scientific specialists but involved in work and debates related to the CTBT. The aim of the report is to help facilitate the assessment of progress in implementing ideas presented at the SnT2023 conference and to foster new projects among the concerned community of scientists.

1.2. CTBT: Science and Technology Conferences as a Continuous Process

In order to build and strengthen its relationship with the broader science community in support of the CTBT, the CTBTO invites the international scientific community to conferences on a regular basis. SnT2023 was the seventh such conference since 2011. These multidisciplinary scientific conferences attract scientists and experts from a broad range of CTBT verification technologies, from national agencies involved in CTBT related work, including staff at National Data Centres (NDCs) and station operators to academic and research institutions. Members of the diplomatic community, international media, civil society and youth also take an active interest.

These SnT conferences are part of a continuous process of engaging the global scientific community. The aim of this process is to ensure that the CTBT verification regime can benefit from current scientific and technological developments in relevant fields. Delivering presentations on specific scientific developments discussed at SnT conferences to Working Group B (WGB), the verification related working group of the CTBTO, is one facet of this process. WGB expert groups on verification related topics, the progressive enhancement of technical capabilities within the verification mandate of the CTBTO and the workshops and training programme of the organization, all interact with the SnT process in various ways.

The SnT process takes into account the Treaty's recognition of the need to progressively enhance the efficiency and cost effectiveness of its verification regime. It also considers the Treaty's recognition that it may be appropriate to have a formal mechanism after its entry into force to solicit external scientific advice on the enhancement of the technical capabilities of the verification regime. Many new and novel scientific instruments, methods and ideas continue to resurface as part of contributions to successive SnT conferences, often in presentations by the same authors or from the same research institutes. Where appropriate, these research ideas may make their way through development, testing and implementation, with a view to being incorporated into provisional operations at the Provisional Technical Secretariat (PTS). In other cases, and considering Treaty provisions, it may be more appropriate for States Signatories to develop technologies in support of their own verification efforts.

Beyond this, new opportunities for civil and scientific applications of IMS data may emerge from the presentations and discussions at the conference. With a focus on the needs of the CTBT verification regime, specific contributions are identified accordingly in Chapters 3 and 4 and all content that was found to be most relevant is summarized in Chapter 6.

1.3. Conference Goals

The SnT2023 conference had four goals:

1. Identify opportunities and methods to improve nuclear-test-ban monitoring and on-site inspection (OSI).
2. Demonstrate how scientific developments and cooperation can support national needs, frame policy objectives in support of the CTBT and promote its universalization.
3. Broaden, connect, and strengthen the scientific communities working in nuclear-test-ban monitoring and OSI, including young scientists, and enhance the geographical and gender representations of these communities.
4. Promote civil and scientific applications, capacity building and training related to CTBT techniques and data.

1.4. Themes and Topics

The following topics were covered by SnT2023 under five themes:

Theme 1: The Earth as a Complex System

1.1 The Atmosphere and its Dynamics
Convenors: Daniela Veronica Ghica, *Scientific Programme Committee (SPC)*; Robin Schoemaker, *CTBTO Preparatory Commission*

1.2 The Solid Earth and its Structure
Convenors: Michelle Grobbelaar, *SPC;* Gerhard Graham, Sherif Ali and Ehsan Qorbani, *CTBTO Preparatory Commission*

1.3. The Oceans and Their Properties
Convenors: Silvia Blanc, *SPC*; Georgios Haralabus, *CTBTO Preparatory Commission*

1.4. Multidisciplinary Studies of the Earth's Subsystems
Convenors: Dmitry A. Storchak and Peter G. Brown (abstract review), *SPC*; Pierrick Mialle, *CTBTO Preparatory Commission*

Theme 2: Events and Nuclear Test Sites

2.1. Characterization of Treaty-Relevant Events
Convenors: Mohamed Nabil Mohmed ElGabry, *SPC*; Boxue Liu and Mario Zampolli, *CTBTO Preparatory Commission*

2.2. Challenges of On-Site Inspection
Convenors: Gustavo Haquin Gerade, *SPC*; Peter Labak, *CTBTO Preparatory Commission*

2.3. Seismoacoustic Sources in Theory and Practice
Convenors: Atalay Ayele Wondem, *SPC*; Paulina Bittner, *CTBTO Preparatory Commission*

2.4. Atmospheric and Subsurface Radionuclide Background and Dispersion
Convenors: YIM Man-Sung, *SPC*; Jolanta Kuśmierczyk-Michulec and Jonathan Baré, *CTBTO Preparatory Commission*

2.5. Historical Data from Nuclear Test Monitoring
Convenors: Anna Berezina, *SPC*; Martin Kalinowski, *CTBTO Preparatory Commission*

Theme 3: Monitoring and On-Site Inspection Technologies and Techniques

3.1. Seismic, Hydroacoustic and Infrasound Technologies and Applications
Convenors: Yoshiyuki Kaneda, *SPC*; Benoit Doury, *CTBTO Preparatory Commission*

3.2. Radionuclide Technologies and Applications
Convenors: Ricardo Sagarzazu, *SPC*; Nikolaus Hermanspahn, *CTBTO Preparatory Commission*

3.3. On-Site Inspection Techniques
Convenors: Gregor Malich and Aled Rowlands, *CTBTO Preparatory Commission*

3.4. Integrating Data from Different Monitoring Technologies
Convenors: Ian Hoffman, *SPC*; Megan Slinkard, *CTBTO Preparatory Commission*

3.5. Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data
Convenors: Paul Richards, *SPC*; Christos Saragiotis, *CTBTO Preparatory Commission*

3.6. Analysis of Radionuclide Monitoring Data
Convenors: Anders Ringbom, *SPC*; and Abdelhakim Gheddou, *CTBTO Preparatory Commission*

Theme 4: Sustainment of Networks, Performance Evaluation and Optimization

4.1. Performance Evaluation of the International Monitoring System and On-Site Inspection and their Components
Convenors: Anne Strømmen Lycke, *SPC*; Thierry Heritier and Josep Vila, *CTBTO Preparatory Commission*

4.2. Systems Engineering for International Monitoring System and On-Site Inspection
Convenors: Oladoyin Odubanjo, *SPC*; Irene Bianchi, *CTBTO Preparatory Commission*

4.3. Enabling IT Technologies
Convenors: Aristide Aly Boyarm, *SPC*; Vera Miljanovic Tamarit, *CTBTO Preparatory Commission*

4.4. International Monitoring System Sustainment
Convenors: Paola García Peña, *SPC*; Xyioli Perez and Guillermo Rocco, *CTBTO Preparatory Commission*

4.5. On-Site Inspection Team Functionality
Convenors: LI Peng, *SPC*; Franz Ontal, *CTBTO Preparatory Commission*

Theme 5: CTBT in a Global Context

5.1. CTBT Science and Technology Policy
Convenors: Marino Protti Quesada, *SPC*; Karli Seshadri, *CTBTO Preparatory Commission*

5.2. Synergies with Global Challenges
Convenors**:** Kathy Whaler and Alexey Malovichko (abstract review), *SPC;* Gérard Rambolamanana, *CTBTO Preparatory Commission*

5.3. Regional Empowerment
Convenors: Nortin Titus, *SPC*; Misrak Fisseha, *CTBTO Preparatory Commission*

5.4. Outreach
Convenors: Magdalene Wangui Wanyaga, *SPC;* La Neice Collins *CTBTO Preparatory Commission*

1.5. Report Structure

The structure of this report follows the scientific conference programme. At the beginning of the report, an introduction is given to SnT2023 in the context of the CTBTO science and technology process (Chapter 1). The high level opening session is covered in Chapter 2. All panel discussions and invited talks are detailed in Chapter 3. The account of scientific contributions (Chapter 4) is organized according to the conference themes, and topics within those themes, as listed in Section 1.4. The chapter sections vary in length. This reflects the distribution of topics covered by submitted abstracts. All closing remarks made during the closing session are presented in Chapter 5. The awards are summarized in the same chapter. The final chapter (Chapter 6), on relevance to CTBTO activities and verification science, reviews the conference highlights and discusses potential focus areas for the future. The substructure of Chapter 6 is different from the themes and topics and more consistent with the logic of CTBTO work areas and partly follows the data flow: from measurement technologies through propagation of signals, data processing and analysis to interpretation and the broader context. The sections are 6.1. Measurement Technologies, 6.2. Earth Characterization and Propagation of Signals, 6.3. Processing of Data, 6.4. Historical Data and Events, Event Physics and Screening Methods and

6.5. CTBT in the Broader Context. Each of these sections includes relevant material on global monitoring using the IMS, as well as local scale activities for OSI, and non-CTBTO or novel methodologies to be applied by a broader community as appropriate. Appendix 1 contains a list of the Scientific Programme Committee members, Appendix 2 summarizes the Side Events and Workshop, Appendix 3 lists all exhibits and sponsors and Appendix 4 provides event statistics.

1.6. Online Availability of Conference Material

This report and all other conference material is available on the SnT2023 conference portal which is accessible through the Science and Technology conference series link on the CTBTO public web site. The SnT2023 Conference Programme and Book of Abstracts are complementary to this report. All oral, one-minute lightning talks and e-poster presentation files are available on the conference portal and can be accessed directly through the hyperlinks provided with the identification numbers mentioned in this report. Hyperlinks are also provided for invited talks and panel discussions. SnT2023 photos can be found on the CTBTO Flickr account, More Photos – SnT2023 album, and the video recordings of all streamed sessions are available on the CTBTO YouTube Channel.

Information on previous SnT conferences and reports on SnT conferences are also available through the CTBTO public web site. As the SnT process evolves, the online record is moving towards an integrated repository of past SnT conferences. A search function has been implemented that allows users to search by keywords through presentations made at all conferences of the SnT series. This will be especially useful for tracking the progress of relevant research initiatives and projects.

The April 2023 issue of the journal *Pure and Applied Geophysics* (PAGEOPH*)* was published as a topical issue capturing selected relevant developments presented at SnT2021 with guest editors from the PTS. This volume entitled "Innovation in Technology and Scientific Methods for Nuclear Explosion Monitoring and Verification" contains 18 papers most of which were already published online in 2022. Based upon the success of the previous issues, the next topical issue gathers again into a single repository a number of peer-reviewed papers from a selection of presentations made at SnT2023 about the latest technological and scientific advances and innovations in nuclear explosion monitoring and verification. The topical issue of PAGEOPH prepared for SnT2023 will have the title "Nuclear Explosion Monitoring and Verification: Science and Technology to Tackle Global Challenges".

2.
High Level Opening

2. High Level Opening

The conference began with a High Level Opening on the morning of 19 June moderated by Monika Jones, an anchor for Deutsche Welle TV, and featured welcoming remarks from Mr Robert Floyd, Executive Secretary of the CTBTO Preparatory Commission. This was followed by several other high level speakers and the session concluded with a High Level discussion on the theme, "CTBT Science and Technology: Benefitting Us All."

For the first time, the High Level Opening was offered with interpretation into all languages of the Commission (Arabic, Chinese, English, French, Russian and Spanish,) for a truly global and inclusive experience.

2.1. The Power of Together: Opening Remarks by the Executive Secretary of the CTBTO Preparatory Commission

Foreign Minister, Excellencies, scientific experts from around the world, colleagues and friends from around the world, It is a great pleasure to welcome you to the CTBT: Science and Technology 2023 conference, in this magnificent venue, the Hofburg.

Executive Secretary Dr. Robert Floyd

This amazing building was built centuries ago, and its elaborate ceiling, bearing the weight of sculptures and carvings, will look down on fine events like this for even more generations and centuries to come. The people who built the Hofburg had no computers. No email. No fancy design programmes. They had no calculators. No laser gadgets. No power tools. But what they did have was a way to measure things. They measured exactly what needed to be done, to design and build this hall. Then they measured exactly how they were doing it. And here's the point. They could measure exactly because they had agreed standards of measurement.

Exactly two hundred and twenty-four years ago, on 22 June 1799 in Paris, not long after the French Revolution, something happened that changed the world. A metal bar representing a new standard measure called 'the metre' was deposited in the National Archive. That bar had been carefully calculated to one/ten millionth of the distance between the equator and the North Pole. Copies of the bar were displayed on walls around Paris so that people could see what this new metre length looked like. And they started using it.

The bar sets the standard for measuring other things and it caught on around the world. Science needs systematic measurement and systematic standards. Not just for distance but also for time, mass, temperature, force and stress, magnetism, electric current and radiation. The principle stays the same: there is no measurement without an agreed standard of measurement. You cannot be accurate without a standard for accuracy!

Nowadays, things have moved on. We do not use that metal bar to define a metre. Instead, we set the standard as the distance light travels in just under one/three hundred millionth of a second. International standards have replaced national or local standards to ever-greater levels of sophistication. Internationally recognized bodies set up under treaty keep those many standards in good order.

This is why this gathering here and online has such symbolic and practical significance. We at the CTBTO have helped bring together two thousand scientists, technical experts and academics from around the world who use these standards. And mixed with this technical audience we have diplomats who represent States around the world who have agreed to treaties and conventions that set the legal and policy framework so that those standards apply everywhere.

This conference also brings together participants from 148 countries: think about all the different languages and cultures. Yet we have one common language: the language of our internationally agreed scientific standards. Excellencies, colleagues, friends, this is *the Power of Together.*

This is what the CTBTO represents. The CTBTO's mission stems from the simple obligation spelled out in Article One of The Comprehensive Nuclear-Test-Ban Treaty:

Our job is to check for signs that this obligation has been betrayed. We use sophisticated sensors and sophisticated measurements

"Each State Party undertakes not to carry out any nuclear weapon test explosion or any other nuclear explosion, …"

to detect possible nuclear explosion tests anywhere, any time on Earth. We are very skilled at detecting any explosion that might be a nuclear explosion. This makes them so much less likely to happen. Plenty of other national organizations and institutions around the world closely monitor seismic and other activity. They too can distinguish between an earthquake and a possible nuclear test.

But the CTBTO is unique. We gather seismic data, measuring vibrations in the Earth's crust. Seismometers measure velocity in metres per second. They are carefully aligned with the geographic North: that allows us to determine the precise direction of arrivals. We gather hydroacoustic data, measuring vibrations in the oceans. We gather infrasound data, measuring vibrations in the air. And we gather radionuclide data, looking for radioactive particles and gases from a nuclear explosion. There is nothing else like this on Earth. It is not just that we bring all this data together and then analyse it speedily, to formidable levels of accuracy. We are international. Our work is even-handed and transparent. All that data is available to all our States Signatories, and so can be shared by the world's wider scientific community.

So, I say loud and clear to everyone here today, scientists and diplomats alike: together we represent global teamwork at its finest. We

share a simple political and moral goal: no more nuclear tests. And we share the best available technical ways to make sure we reach that goal. The CTBTO is set up under the Treaty, with a global network of scientists who support this goal and who invent smart new ways to ensure we reach that goal.

The Power of Together.

Let us look at what our conference this week is contributing. One technology we use is infrasound and an exciting feature of this year SnT is a metrology workshop. Experts will discuss recent successes on robust calibration practices for infrasound technology. By agreeing to a new way to link the power of our technology to an agreed standard for measuring what we're doing, we open the way to all sorts of new developments.

This is how the CTBTO and you, our wider scientific family, help define the philosophical frontiers of science to get things done in new and better ways. Our work is all about extracting signal from noise. Our planet makes a lot of noise and we have to follow it, to spot anything in it that might be a nuclear explosion. Our machines and technologies – the machines you helped invent – keep getting better and better and more and more 'sensitive'. So does our software for analysing it all. This conference celebrates how this can work in practice. Our global network of sensors followed the impact of the Hunga Tonga eruption last year. We measured it using all three waveforms - the vibrations went round the planet several times.

Other highlights of this conference? New technology for our on-site inspections. Sensors and monitors do so much - from a distance. But the Treaty also provides for scientific experts to visit the site of a suspected test, to run first-hand checks on and in and above the ground. Their instruments can rule in and rule out evidence of illicit nuclear test activity. There is a powerful exhibit here featuring a helicopter frame, and screens that show what might be done from the air.

Here is another example of the *Power of Together*. Most major scientific gatherings are not like the SnT. They bring together experts in one or maybe two disciplines and focus on depth, not breadth. But this event is completely different, bringing together so many different disciplines. Seismology, acoustics, meteorology, radiation physics, information technology and software engineering. Representatives of twelve different scientific societies are joining us this week.

This is a hugely important opportunity for thinking outside the box: for seeing how many other boxes there are to explore; thinking of ways to combine different boxes; and to gather ideas for making completely new boxes. In short, here in Vienna today is a meeting of global 'team science'. It is taking place to advance one of the great technical and moral issues of our time: ending nuclear explosions.

The Power of Together.

My central idea – *the Power of Together* – is not complete. We need a standard for who counts when we measure 'Together'. Much of the world's scientific leadership has traditionally come from only certain parts of the world, and from one category of people – namely men. That has to change - and it is changing. The CTBTO is working hard to broaden its own internal representation and its outreach. You will see this at this conference, with different language panels, presentations from experts from across the world and keen participation by young people. And please, especially women and participants from less represented nationalities, get inspired and think about applying to join the Secretariat.

How to sum it all up? The Comprehensive Nuclear-Test-Ban Treaty is a treaty for the world. 186 States have signed the treaty. 177 States have ratified it. More ratifications are in the pipeline. Sri Lanka completed the ratification process just two weeks ago. It is my pleasure to tell you that on the 9 June,

the House of the Parliament of Papua New Guinea agreed to ratify the CTBT. You feel the momentum - and there are more in the pipeline. This is not done yet.

Before 1996 when the Treaty was agreed, there had been over two thousand nuclear explosion tests around the world. On the ground, under the ground, in the sea and in the air. Since 1996 there have been less than twelve tests. In this century? Only by one State. By any standard of policy and practice, by any measure of success, this is success and on a grand scale.

It happened because the world's States agreed that enough was enough. But it needed both science and diplomacy. The scientists showed that remote verification of nuclear tests was robust and reliable, whilst the diplomats were able to agree on the Treaty. This was the *Power of Together*, that you all here today represent.

We *together* use the best possible standards of measuring. And when necessary, we agree on new robust standards. Then we *together* measure in incredible detail what is going on. We *together* analyse in incredible detail what's going on. And we *together* know in incredible detail what's going on. We are very good at what we do. And, as each year passes, we are getting better and better.

I finish with a quote from someone who was both a towering scientist and something of a diplomat, just the right person to guide us today. Leonardo Da Vinci: *"Truth at last cannot be hidden. Nothing is hidden under the sun."* Thank you.

2.2. High Level Speakers

The high level speeches started with a video message from Ms Izumi Nakamitsu, United Nations Under-Secretary-General and High Representative for Disarmament Affairs (remarks by Ms Izumi Nakamitsu); continued with remarks by Mr Rafael Grossi, Director General of the International Atomic Energy Agency (remarks by Mr Rafael Grossi); His Excellency Mr Abshir Omar Jama Huruse, Minister of Foreign Affairs & International Cooperation of Somalia (remarks by Mr Abshir Omar Jama Huruse); Mr Mayen Dut Wol, Undersecretary of the Ministry of Foreign Affairs and International Cooperation of South Sudan (remarks by Mr Mayen Dut Wol); Ms Alinne Olvera Martínez, a youth representative and alumna of the CTBTO Mentoring Programme (remarks by Ms Alinne Olvera Martínez) and concluded with Ms Jill Hruby, Under Secretary for Nuclear Security of the United States Department of Energy and Administrator of the National Nuclear Security Administration (NNSA) (remarks by Ms Jill Hruby).

In welcoming attendees from around the world, Executive Secretary Robert Floyd highlighted the important role science plays in bringing communities together. "148 countries [are represented here]: think about all the different languages and cultures. Yet we have one common language: the language of our internationally agreed scientific standards... This is the *Power of Together*. This is what the CTBTO represents."

In her video message, Ms Izumi Nakamitsu noted that the power of innovation in different fields and the synergic connections between them can contribute to creating a world without nuclear weapons. She also commended SnT2023 for serving as "a valuable opportunity for representatives from different fields to engage one another and exchange experiences and practices to improve verification capabilities and promote their role in strengthening the Treaty and supporting national needs."

Senior officials from Somalia and South Sudan expressed their appreciation for the convening of the scientific community and reiterated their commitment to the Treaty. Mr Abshir Omar Jama Huruse said, "I am filled with admiration for the convergence of over a thousand brilliant minds – scientists, researchers, technology experts, academics, diplomats, government officials, civil society

Izumi Nakamitsu

Rafael Grossi

members and aspiring youth. This collective pursuit of knowledge and progress in the field of the Comprehensive Nuclear-Test-Ban Treaty is truly inspiring. Today, we gather not only to celebrate intellect, but also to embrace the harmony of science and diplomacy, united for the noble cause of global peace and security."

He added that Somalia was committed to becoming a CTBT State Signatory as part of their contribution toward a more peaceful and harmonious world, saying, "Signing and ratifying the CTBT is not merely a symbolic gesture, but a testament to our unwavering dedication to global peace and security." The country acceded to the Treaty soon after, depositing its instrument of ratification on 8 September 2023.

Mr Mayen Dut Wol also highlighted the importance of global solidarity in achieving a world free of nuclear testing. "Together, we can build a future where the devastating impact of nuclear tests is forever eradicated. Furthermore, we are resolute in our commitment to foster partnerships and collaborations that facilitate exchange of expertise, training and resources, and in this regard, we would be interested in pertinent technical cooperation and support to strengthen capacity building of our national experts including in areas of CTBTO comparative advantage. By empowering our scientists, researchers and technicians, we can actively contribute to global efforts in nuclear disarmament and the peaceful uses of nuclear energy."

He also pledged South Sudan's support to the CTBT and to advancing nuclear non-proliferation and disarmament, "[We are]

Abshir Omar Jama Huruse

Jill Hruby

keen to sign and ratify the Treaty as a commitment to international peace and security in the nearest time."

Ms Alinne Olvera Martínez, scientist, researcher and former participant in the CTBTO Mentoring Programme for early career women in the fields of science, technology, engineering and mathematics (STEM), issued a rousing call to action to attendees of all generations for the inclusion and empowerment of youth. "The importance of nurturing and empowering young minds in the field of science cannot be overstated. The future of scientific progress and global peace lies in the hands of the next generation. To the young people listening to me: have confidence in your ability to influence decisions and create a positive impact in your countries and on the international stage. Let your participation make a difference. Today, I encourage you to assume responsibility, and to lead the way towards the prohibition of nuclear testing. Our participation is non-negotiable."

The high level speeches concluded with a keynote address from Ms Jill Hruby who stressed that the need for the CTBT and its verification regime were more important than ever and applauded the Executive Secretary's tireless efforts to achieve more ratifications. She addressed the importance of the CTBT in the global non-proliferation regime as well as the strong US commitments to the CTBT, maintaining the US stockpile while continuing to observe its nuclear explosive testing moratorium, and demonstrating transparency as a responsible nuclear power. Ms Hruby offered several ideas on transparency into the nuclear weapons and non-proliferation programmes of NNSA,

Mayen Dut Wol

Alinne Olvera Martínez

including hosting international visitors at the Nevada National Security Site to better understand how subcritical experiments and chemical high explosive tests are in fact not nuclear explosive tests. NNSA provides pre-shot notification of events at the Nevada National Security Site, and publicly shares data and findings from chemical high explosive tests. NNSA is even open to working with others to develop a regime that would allow reciprocal observation with radiation detection equipment during subcritical experiments to show consistency with the CTBT.

2.3. High Level Discussion on the Theme, "CTBT Science and Technology: Benefitting Us All"

The opening session of SnT2023 was followed by a High Level discussion on the theme, "CTBT Science and Technology: Benefitting Us All." The panel consisted of five distinguished experts who delved into the various ways the IMS benefits humanity, including the civil and scientific applications of its data.

Having helped negotiate the Treaty as a delegate to the Conference on Disarmament in Geneva in the 1990s, the first panellist, Ambassador Li Song, Permanent Representative of the People's Republic of China to the United Nations and other International Organizations in Vienna, shared his extensive knowledge of the Treaty. He noted that the years after the Cold War were considered a 'golden age' for multilateral arms control and disarmament efforts, so this was an opportune time to begin negotiations on the CTBT. "We put all our different ideas and concerns together and worked on them and eventually we addressed each and every national concern and came up with all those

necessary provisions for this Treaty." He added that it was the power of looking ahead toward a common goal for all the countries involved in the negotiations that resulted in the CTBT, and he retains the conviction today that we can achieve a Treaty like the CTBT.

Ms Xyoli Pérez Campos, Director of the IMS Division, noted that the wealth of data collected by the IMS can be used by States Signatories and scientists and researchers for civil and scientific applications. "This is very exciting. As a scientist, when I see this data and I see people are using it, it's just wonderful. To see a very committed team of people working every day to have this high quality data available to the world is just amazing."

Ms Dwikorita Karnawati, Head of the Indonesian Meteorology, Climatology, and Geophysics Agency and chair of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System, shared insights into the application of CTBTO data for disaster risk mitigation in the area of tsunami early warning systems. She described the impact that having access to IMS data has had for her country. "We now have truly systematic measurements to support timely, accurate, early warning systems. Hopefully through CTBTO we can get stronger and save more people."

Ms Antonietta Rizzo, Head of the Laboratory for Methods, and Techniques for Nuclear Safety, Monitoring and Traceability, Italian National Agency for New Technologies, Energy and Sustainable Economic Development, told participants that one of the many benefits of having access to CTBTO data was that it could be shared with university students to use in their research and they can then showcase their work to a larger community. "The students present their research for their final examinations, and they discuss it in front of their teachers, but also in front of their friends, family, siblings, and so now in our city we have a community of civil society that knows about CTBTO's verification regime and International Monitoring System. This is very important so that real people know what we are doing in our work." Ms Rizzo said the data, along with the research it supports, contributes to their ability to attract younger people and more diverse scientists to the fields of nuclear non-proliferation and disarmament.

While many conference attendees work in the scientific fields related to CTBTO's verification regime, Geoff Brumfiel, Senior Editor and Correspondent for National Public Radio's science desk, said that during a time of rampant misinformation, the data provided by CTBTO is more important than ever for a wider audience. "One of the key things is the fact that IMS data is available to academics in Member States and often those academics are the ones that provide it to the public, that end up talking about it with the public, but underpinning it is the CTBTO. So, it's been really key for several really important stories I've covered over the past few decades."

3. Panel Discussions and Relevant Invited Talks

3. Panel Discussions and Relevant Invited Talks

3.1. High Level Panel Discussions

The panels summarized in this chapter are according to the numbering in the conference programme. All panels are represented with the list of speakers and moderators with their affiliations and a short summary of the highlights of the discussions.

3.1.1 European Union–CTBTO Cooperation in Action

Pa1.1 **Panel Discussion on European Union–CTBTO Cooperation**

Opening Remarks: Ambassador Stephan Klement, *Head of the Delegation of the European Union to the International Organisations in Vienna*

Moderator: Elena Thoma, *Delegation of the European Union to the International Organisations in Vienna*

Panellists: Alessandro Cortese, *Permanent Representative of Italy to the International Organizations in Vienna*
Bruno Lebret, *Commissariat à l'énergie atomique et aux énergies alternatives, France*
Ricardo Jose Lopez Rubio, *Fundacion Venezolana de Investigaciones Sismologicas, Venezuela*
Sri Sundari Retnoasih, *National Research and Innovation Agency, Indonesia*
Takalani Cele, *Non-Proliferation Secretariat. South Africa*

Closing Remarks: Robert Floyd, *Executive Secretary of the CTBTO*

The European Union remains a staunch supporter of the CTBT and its organization, both politically and financially. Promoting the universalization and entry into force of the CTBT is a top priority for the European Union, in line with its non-proliferation and disarmament policies and objectives. Within the framework of the European Union Strategy against the Proliferation of Weapons of Mass Destruction, the European Union has provided voluntary contributions to the CTBTO through eight European Union Council Decisions in order to strengthen its monitoring and verification capabilities.

In his opening remarks, Ambassador Stephan Klement described the extensive support provided by the European Union for the Treaty and its verification regime.

Ambassador Alessandro Cortese described the importance of the cooperation between the European Union and the CTBTO from the perspective of a European Member State and from his experience as an Article XIV Co-Coordinator, outlining why outreach to non-signatory States and non-ratifying countries including Annex 2 States and capacity building of youth, parliamentarians, journalists and scientists is critical.

Mr Bruno Lebret presented the contribution of the Commissariat à l'énergie atomique et aux énergies alternatives to the development of software tools for seismic, hydroacoustic and infrasound analysis. He shared with the audience three concrete examples of the benefits of using NDC in a box to perform analysis of seismic, hydroacoustic and infrasound data. He closed by reiterating the interest of his organization in further collaborating with the CTBTO and shared his perspective on this future collaboration.

Mr Ricardo Lopez Rubio who is the station operator at AS118 (Puerto de la Cruz, Venezuela) explained the direct impact of the programmes funded by the European Union through the CTBTO on the maintenance and the upgrading of the seismic station AS118, allowing for a continuous and improved monitoring of events. He mentioned two particular incidents where the contribution from the European Union was a key factor, and explained how AS118 has already contributed to the global efforts in monitoring nuclear explosions around the world, resulting in his organization being a key player in the framework of the CTBT.

Ms Sri Sundari Retnoasih (nuclear safeguards officer, CTBTO Youth Group (CYG) and mentee as emerging female expert) shared her experience as a participant of the OSI linear training programme by attending both the Regional Introductory Course 24 in Thailand and Regional Introductory Course 25 in Slovakia. She emphasized the benefit of this participation on her career, on Indonesia's involvement in CTBTO activities and on the technical support she is now in the position to provide to the Permanent Mission of Indonesia to the International Organizations in Vienna.

Ms Takalani Cele (physicist) benefited from the pilot project and attended the Fifty-Fourth Session of WGB in 2020. She shared with the audience the impact of this experience on her understanding of the verification regime and the work of the CTBTO, and how she was able to use the outcomes of the WGB Session to provide improvement guidelines to RL14. She also described how South Africa can benefit from civil and scientific applications of waveform data from the IMS.

In his closing remarks, Mr Robert Floyd stressed the importance of the long standing partnership between the European Union and the CTBTO and expressed his acknowledgements to the European Union and to all panellists.

3.1.2 L'apport de la francophonie dans les discussions internationales

Pa1.2 **Panel Discussion on Francophonie**
Moderator: Agnès Chanut, *Le Cercle, Vienne*
Panellists: Caroline Vermeulen, *Représentante permanente de la Belgique auprès des Organisations Internationales à Vienne*
Delphine Hournau-Pouëzat, *Représentante permanente de la France auprès des Organisations Internationales à Vienne*
Gueu Albert Dole, *Charge d'Affaire de la mission permanente de Côte d'Ivoire en Autriche*
Henri Monceau, *Représentant permanent de l'Organisation internationale de la Francophonie auprès des Organisations Internationales à Vienne et à Genève*

The first day of SnT2023 continued in the afternoon with a panel discussion in French on "L'apport de la francophonie dans les discussions internationales". The panel reviewed how essential multilingualism is to international discussions as a means to better balance the exchange of ideas and international relations. The French language spoken in various countries of the Organisation internationale de la francophonie, but also beyond it, specifically in diplomatic circles, was used to illustrate the concepts discussed. Her Excellency Ms Vermeulen first reminded the audience that at the United Nations there are six official languages, and for this panel discussion in the Hofburg Palace interpretation in official languages is occurring. Obviously, interpretation comes with a cost that may not be negligeable, however, monolingualism means that many delegations do not negotiate in their mother tongue, which poses a real challenge in terms of accuracy, rigour of thought, nuances and effectiveness of debates and understanding. In a way, monolingualism prevents discussions from being inclusive. In order to go beyond the language barriers but also beyond traditional regional groups, a group of francophone ambassadors, (groupes des ambassadeurs francophones) was created. This group exists in Vienna, the groupes des ambassadeurs francophones de Vienne, which allows a step to be taken towards more inclusivity and better understanding between regions with different cultures.

His Excellency Mr Monceau added that in addition to the groupes des ambassadeurs francophones, the role of the Organisation internationale de la francophonie is to advance progress on a number of cross-cutting issues, such as multilingualism, which in turn is of benefit to multilateralism. The Organisation internationale de la francophonie was created on the African continent to offer a multilateral outlet to French speaking countries. Nowadays it has 54 Member States and a total of 88 States when associated and observatory States are taken into account.

His Excellency Mr Dole elaborated further on this concept with the example of the African group, which is a multilingual group that successfully operates by organizing consultations among all States without consideration of a linguistic basis.

Her Excellency Ms Hournau-Pouëzat built on the examples provided by other panellists to insist that multilingualism be the ambition of universality, which is also the goal of the Treaty. Multilingualism is a fundamental value of the United Nations, it contributes to the achievement of international peace and security, to the achievement of the development of friendly relations between nations and to the achievement of international cooperation. The panellist highlighted the importance of the technical cooperation between the CTBTO and States Signatories, such as with international and regional workshops, some of them delivered in French, Arabic or Spanish. In that sense, multilingualism contributes strongly to improving the results, efficiency and transparency of the activities of the CTBTO.

The panel participants insisted on the essential need to utilize multilingualism to provide openness and quality of listening within the multilateral system to allow the most effective and true discussions. In this regard the panel emphasized the recent progress of the PTS in expanding the translation service to expert groups organized at the margins of WGB. The panellists encouraged the CTBTO to go beyond multilingualism in official meetings, by writing documents in other official languages. Recent technological innovations are opening this possibility in an efficient and more cost effective way.

3.2. Scientific Panel Discussion and Relevant Invited Talks

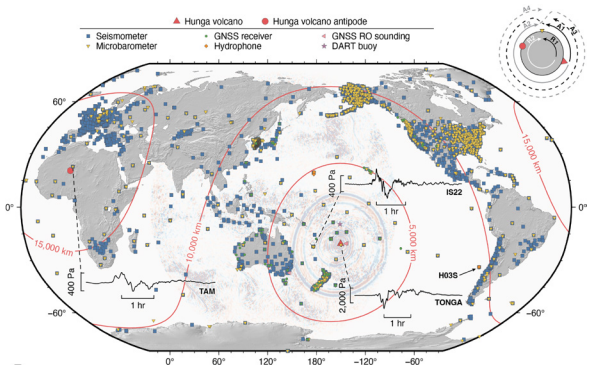
3.2.1 Hunga Tonga-Hunga Ha'apai Eruption and Tsunami: A Multi-Phenomenon Event

Invited Presentation Series on Large Seismoacoustic Events

I2.1-754 **Invited talk on Global Seismoacoustic Observations of the Remarkable Atmospheric Waves from the January 2022 Hunga Tonga-Hunga Ha'apai Volcanic Eruption**

Invited Speaker: David Fee, *University of Alaska Fairbanks, USA*

The 15 January 2022 climactic eruption of the undersea Hunga Tonga-Hunga Ha'apai volcano (the Hunga eruption), Tonga, produced an explosion in the atmosphere of a size that has not been documented in the modern geophysical record. The eruption generated tsunamis, regional ashfall and plume that reached stratospheric heights (55km). The event generated a broad range of atmospheric waves observed globally

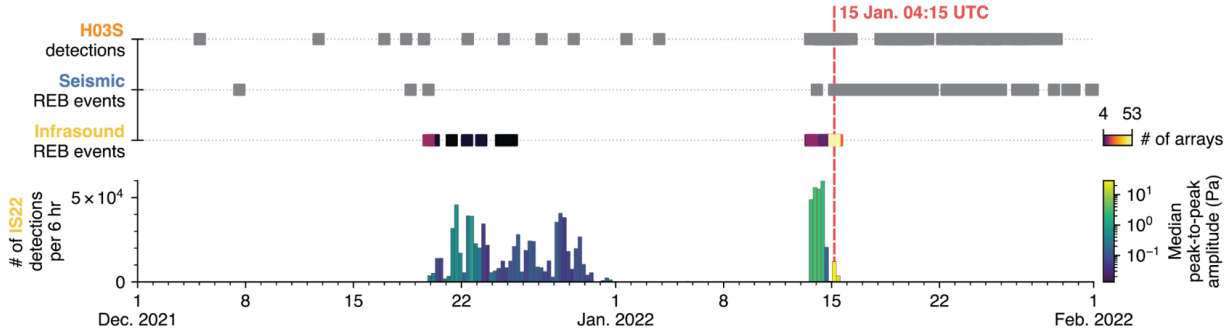


*I2.1-754: Global distribution of recording geophysical sensors used in the study and remotely observed eruption chronology. **Map** including all sensors used for the study; background image is brightness temperature difference (Himawari-8) at 07:10 UTC on 15 January 2022; and selected 4-hour pressure waveforms are filtered from 10,000 to 100 s. Upper-right shows Hunga wave paths around Earth*

From Robin S. Matoza et al., Atmospheric waves and global seismoacoustic observations of the January 2022 Hunga eruption, Tonga. Science 377, 95-100 (2022). DOI:10.1126/science.abo7063. Reprinted with permission from AAAS.

by various ground based and spaceborne technologies and instrumentation networks.

The most notable atmospheric wave was the surface-guided Lamb wave (≲0.01 hertz), which is an acoustic-gravity wave that is associated with extremely large atmospheric explosions. The Lamb wave was detected on barometers, infrasound sensors, seismometers and satellites. This Lamb wave propagated around the globe numerous times and observations of at least four (plus three antipodal) passages around the Earth over six days were extracted. The Lamb wave contributed to fast arriving, hazardous tsunamis that were not forecasted.



I2.1-754: ***Top*** *Hunga volcanic activity, from December 2021 through January 2022, observed at IMS hydrophone, seismic, and infrasound stations in number of detections or REBs;* ***Bottom*** *Hunga eruption detection chronology per 6 hour bins and colour coded for peak-to-peak amplitude from nearest IMS infrasound array IS22 (at 1850 km distance).*

From Robin S. Matoza et al., Atmospheric waves and global seismoacoustic observations of the January 2022 Hunga eruption, Tonga. Science 377, 95-100 (2022). DOI:10.1126/science.abo7063. Reprinted with permission from AAAS.

The Hunga Lamb wave resembled the Lamb wave produced by the 1883 Krakatau eruption, but it was observed by a much denser instrument network.

The Hunga eruption produced remarkable globally detected infrasound (0.01 to 20 hertz), long range audible sound and ionospheric perturbations. Infrasound waves also propagated around the globe numerous times and audible acoustic waves were heard as far as an unprecedented 9000 km distance. Current wave propagation models do not sufficiently explain these observations. The estimation of an equivalent yield for the eruption is possible, however, it remains challenging due to the inherent properties of the source, which is a long-duration source-time function.

The atmospheric waves from this eruption provide a landmark dataset for scientists to study for many years, with the IMS network being a key element to understand global wave phenomenon. This set of observations is helpful for disentangling the event and understanding the propagation of waves through the atmosphere and ocean.

Pa2.1 Panel Discussion on the 2022 Eruption of Hunga Tonga-Hunga Ha'apai Volcano

Moderator: Geoff Brumfiel, *National Public Radio, USA*

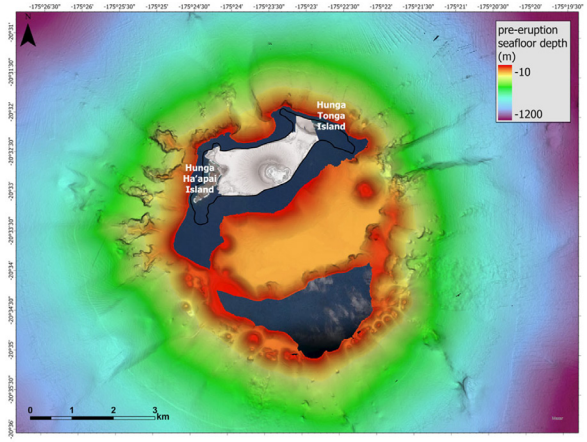
Panellists: David Fee, *University of Alaska Fairbanks, USA*

Margaret Hellweg, *Seismological Society of America, USA*

Stefanie Donner, *Federal Institute for Geosciences and Natural Resources, Germany*

Shane Cronin, *The University of Auckland, New Zealand*

Sara Barsotti, *Icelandic Meteorological Office, Iceland*



Pa2.1: Drastic changes in bathymetry around the Hunga Tonga and Hunga Ha'apai islands before and after the eruption of 15 January 2022.

The 15 January 2022 Hunga eruption in the Tonga Islands (Southern Pacific Ocean) was unprecedented in modern times. It was one of the largest volcanic explosions of the instrumented era and ranks as the most energetic volcanic explosion on Earth since the 1883 eruption of Krakatau (Indonesia). Previous geophysical research on the Hunga Tonga-Hunga Ha'apai volcano's history and morphology suggested that it had the potential for a large catastrophic eruption. However, the 2022 event was of such a scale that it stretches the understanding that is available from modern volcano physics eruption models.

For example, the rate of air pulled in by the plume which rose rapidly to the stratosphere and expanded into a mushroom cloud was so high that it produced a clearly recognizable negative pressure trough in the infrasound signal recordings.

The Hunga eruption was a 'multi-phenomenon' event, which was recorded globally by a large variety of observing systems and by all three IMS waveform monitoring technologies: seismic, infrasound and hydroacoustic. The global reach and massive scale of the eruption makes it a benchmark event; the panellists even referred to it as a "calibration event" for the IMS network capability. The analysis of these synchronized global IMS recordings revealed surprising details about strongly coupled earth-ocean-atmosphere phenomena and have the potential of providing insights and answering open questions about the processes that generated the tsunami which caused devastation at the regional level and was recorded by pressure gauges, tide gauges and hydrophones around the world. Sea level changes from the tsunami were recorded as far as the Mediterranean Sea. The local population in Tonga reported being terrified on hearing the sounds generated by the eruption and explosion, and surprisingly sounds audible to humans were also reported in New Zealand about 2000 km away and even as far as Alaska which is over 9000 km away from the volcano.

Insights from the Hunga eruption dataset pertaining to coupling between earth-ocean-atmosphere also have the potential to lead to improved seismic–acoustic propagation models, which in turn can improve CTBT monitoring and IMS performance prediction.

One notable aspect was that only very small amounts of volcanic ash deposits were found on the ground on nearby islands after the eruption. This was a consequence of the volcano being submerged 150m below sea level at the time of the eruption. Considering the scale of the eruption and explosion, the relatively scarce ash deposits represented a smaller clue than one would expect from a catastrophic event of this scale. This finding has an impact on volcanic hazard assessment and should lead to revisiting the geological history and resulting risks for some known volcanoes worldwide, as until now the assumption was that small amounts of ash deposits would imply a small risk from the eruption.

In terms of volcanic hazard assessment and disaster preparedness worldwide, it was highlighted that a limited number of countries have the means and capacity available for in-situ monitoring of volcanoes that pose potential threats to them and their neighbours. The importance of expanding capacity building and support for volcano monitoring and hazard assessment to larger areas of the world was emphasized. It was also noted that, overall, very little monitoring data is available in near real time globally and there is significant room for improvement of intergovernmental and international cooperation, for data exchange under one umbrella and for common standards.

An initiative launched in 2022 for the recognition of State volcano observatories, and their representation at the United Nations level was welcomed by the panel, noting that the IMS network should be included amongst the relevant capabilities. Other international initiatives would benefit from information provided by the CTBTO, on IMS data or International Data Centre (IDC) products, such as the programme run by the European Emergency Response Coordination Centre. As most volcanoes are submerged underwater and not monitored by in-situ methods, IMS hydroacoustic data can be particularly useful and sometimes it is the only remote monitoring data available. In addition, a large number of active volcanoes that are not submerged are in remote and poorly instrumented locations where IMS infrasound data can be useful in complementing other observation techniques and provide important knowledge of the eruption and its chronology. In conclusion, it was noted that one known volcano located about 20 km north of the Hunga Tonga-Hunga Ha'apai had similar characteristics to the

Hunga eruption in 2015 and should therefore be watched and surveyed for risk monitoring.

3.2.2 Developments in Three-Dimensional Wave Propagation Modelling and Wave Conversion at the Ocean, Land and Atmosphere Interfaces for Infrasound and Hydroacoustic Signals

Pa2.2 **Panel Discussion on Three Dimensional Wave Propagation Modelling**
Moderator: Charlotte Rowe, *Los Alamos National Laboratory, USA*
Panellists: Kevin Heaney, *Applied Ocean Sciences, USA*
Roger Waxler, *National Center for Physical Acoustics*, *University of Mississippi, USA*
Silvia Blanc, *Argentinian Navy Research Office, Argentina*

The CTBT IMS global sensor network comprises three waveform technologies: seismic, hydroacoustic and infrasound, designed to monitor the world continuously for any nuclear explosions on the ground, in the ocean and in the atmosphere. Waveform signals at IMS stations can present complex arrival characteristics caused by three dimensional (3-D) features along their long range propagation paths. Panel 2.2 debated the challenges in 3-D modelling of long range sound propagation in the ocean and in the atmosphere. Moreover, panellists discussed recent advances in 3-D modelling of seismic-to-acoustic and acoustic-to-seismic energy conversion at the ocean, land and atmosphere interfaces. The highlights of the discussion are given below.

Three-dimensional hydroacoustic modelling has made significant advances in the last years and can now be used to support, for instance, CTBTO data analysis (new travel timetables and blockage maps). However, 3-D infrasound modelling is advancing at an earlier stage of development for global range simulations (propagation scales of interest to CTBTO). The 3-D modelling of wave conversion at the ocean, land and atmosphere interfaces is of great interest. but requires more understanding of its physics and is computationally costly.

High performance computing allows for a more realistic simulation of long range propagation of acoustic waves at a global scale using a great amount of input data to model very accurately the propagation medium and its boundaries. The panellists mentioned that the freely available hindcast and forecast data systems have significantly contributed to more realistic simulations. Silvia Blanc highlighted the well known Copernicus system that enables estimation of the sound speed in the ocean at any time of the year, this is particularly useful for areas with a scarce statistical survey of this parameter.

IMS waveform data can be used to support the study of seismic-to-acoustic and acoustic-to-seismic energy conversion at the ocean, land and atmosphere interfaces. These studies are crucial to understanding the physics of energy conversion at interfaces because they are still not fully understood. Moreover, IMS waveform data has the potential to be used to validate and calibrate numerical models simulating energy conversion at interfaces. The panellists also highlighted the need to include dynamic water-atmosphere interfaces and the existence of ice sheets in simulations as they can occur at high latitudes (Arctic or Antarctic icesheet).

3.2.3 Advances in Noble Gas Monitoring and Remaining Challenges for Detecting Nuclear Explosion Signals

I2.3-046 **Invited talk on Final Results of the 1st Nuclear Explosion Signal Screening Open Inter-Comparison Exercise 2021**
Invited Speaker: Christian Maurer, *Geosphere Austria*, *Austria*

The 1st Nuclear Explosion Signal Screening Open Inter-Comparison Exercise 2021 was an important next step in a chain of studies and projects to shed light on resolving the issue of distinguishing for each IMS sample whether an observation can be explained with known sources or whether it possibly contains a

contribution from a nuclear explosion. Nine participating organizations from six countries used seven meteorological data sets and four different atmospheric transport modelling (ATM) models on a synthetic test data set, including concentrations of radioxenon isotopes, measured at 23 IMS station locations mixed with a priori 53 simulated concentrations from hypothetical nuclear tests. The exercise revolved around three questions of which the first was crucial: (1) Is a measurement an anomaly (regardless of what has caused it)? This allowed participants to test their methods for identifying the signals against the background of radioxenon from civil sources. (2) Has an underground or underwater nuclear explosion to be assumed based on isotopic ratios? and (3) Can we determine the release time plus uncertainty within a predefined window?

A key element to the exercise was an inventory of source terms (activities in Becquerel for four CTBT-relevant radioxenons for the year 2014) specifying known civil radioxenon emitters (foremost nuclear power plants and radiopharmaceutical plants). These source terms were used in the participants' choice of ATM method to estimate the concentration (Becquerel per cubic metre) at the relevant IMS station, providing the 'background' field against which the synthetic test 'signals' were to be detected.

Participants provided their estimates of the background for comparison without knowing when and where the synthetic nuclear signals originated. The process of identifying test 'signals' was treated as a detection process in terms of receiver operator characteristic curves that characterize true-positive and false-positive rates of detection. The possibility of using isotope concentrations or isotope concentration ratios as indicative of detection are both considered. The results reported represent a preliminary stage of assessment of the exercise outcome.

I2.3-667 **Invited talk on Radioxenon Monitoring as Crucial Part of the CTBTO Verification Regime: Overview, Status and Challenges**

Invited Speaker: Zeinabou Mindaoudou Souley, *CTBTO Preparatory Commission*

The IMS noble gas system network is unique and atmospheric radioxenon monitoring is a complex task. Currently 26 out of 40 noble gas systems have been installed and are certified. Four different developers have created new generation noble gas systems. These are the SAUNA III, SPALAX- New Generation, Xenon International and MIKS. The roll-out into the IMS network has started. The current generation has a time resolution of 12 or 24 hours per sample. The new generation enhances this to 6, 8 or 12 hours, depending on the system. This results in a more than twofold increase in the number of daily samples to be processed. The IDC software has been completely re-designed and is able to process spectra from all new systems. This applies to the automatic processing with the automatic Software Tool for RAdionuclide Data Analysis (AutoSTRADA) and to interactive review with the iNtegrated Software Platform for the Interactive REview (iNSPIRE).

The noble gas categorization scheme is a three level scheme. It categorizes each sample by its potential interest based on the observed concentrations. Out of more than 140 000 spectra measured in the past decade, about 42% contained radioxenon. Only 3.5% of all samples were highlighted as Level C as they had anomalous concentrations. This reduces the vast number of samples to less than 5000 that contain radioxenon in concentrations not typical for the station site. It should be noted that nuclear explosion signals are not limited to anomalous concentrations. They may just as well be recorded as a Level B sample. With so many radioxenon observations, special care needs to be taken not to miss a potential signal from a nuclear explosion. A new animation on display on the OmniGlobe visualizes how the radioxenon emissions from selected nuclear facilities in the Northern Hemisphere quickly mix with each other. This mix creates the atmospheric background before reaching

IMS stations. Therefore, any release from an unknown source, like a nuclear test, may be difficult to identify.

The big challenges are, first to identify a signal of interest against the widespread and highly variable atmospheric background, then to characterize the event to determine whether the source could possibly be an explosion. The objective of event screening is to discriminate between non-nuclear test observations and those showing features of a nuclear explosion. The IDC is using the following methods for standard products: concentration anomalies are highlighted by event categorization (Level C), scatter plots may reveal further anomalies, two-isotope event screening flags and the 4-isotope plot, associating multiple samples to the same release event, ATM for source location and to implement the "Backtracking to know sources" flag, information about the known sources is required (location, quantity and time pattern of the releases). The currently used publicly available data are insufficient.

The IDC has embarked on implementing in operational software the methods for expert technical analysis to assist a requesting State in characterizing an event. This includes event characterization and timing using the activity ratios.

Despite all the challenges mentioned, noble gas monitoring has demonstrated that it is highly effective. The nuclear tests announced by the Democratic People's Republic of Korea served as a quality check. This area of monitoring science is still highly dynamic and vibrant. Significant scientific and technological opportunities are promising so that noble gas monitoring can make a giant leap forward and be carried out much better than today. This can best be achieved by strong cooperation and strategic planning of the international scientific and technological community.

Pa2.3 **Panel Discussion on Advances in Noble Gas Monitoring and Remaining Challenges for Detecting Nuclear Explosion Signals**

Moderator: Harry Miley, *Pacific Northwest National Laboratory, USA*

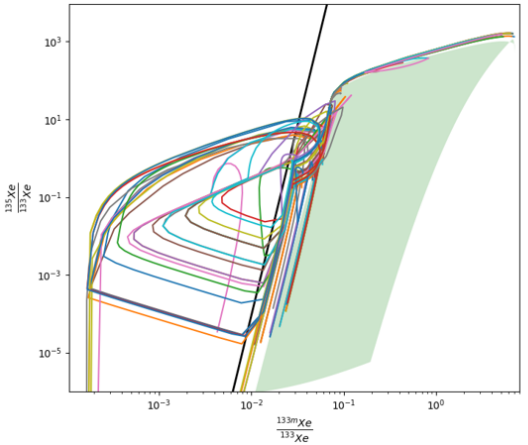
Panellists: Anders Ringbom, *Swedish Defence Research Agency*, *Sweden*

Hong Mo Park, *Korea Institute of Nuclear Safety, Republic of Korea*

Matthew Goodwin, *Atomic Weapons Establishment Aldermaston, United Kingdom*

Sylvia Generoso, *Commissariat à l'énergie atomique et aux énergies alternatives, France*

While the CTBTO is setting up and operating a worldwide network of stations to monitor the globe for evidence of potential nuclear tests, the role CTBT-relevant radioxenons plays becomes more crucial every year as it



Panel 2.3: As explained by Anders Ringbom, the isotopic activity ratios of radioxenon sources still need to be better described. As the figure shows, the discrimination line as tentatively shown in the 4-isotope plot by Kalinowski et al. (2010) is not written in stone. Remaining challenges include improved modelling of release mechanisms for nuclear test explosions and for nuclear facilities.

is these radioxenons that hinder the capacity of the CTBT verification regime. The panel discussed future nuclear technologies as well as how radionuclide expertise and ATM expertise, in combination with next generation sample station equipment, take resolve to better estimate the impact of this persistent radioxenon background made by man. There were five key takeaways from the panel discussion:

The next generation of noble gas systems will improve source location; they will remain large due to the sparseness of the network. We need to do as good a job as we can by

including as much supplementary information as possible and perform data fusion combined with hypothesis testing.

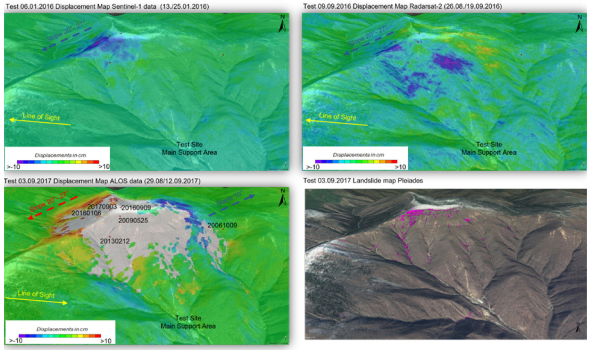
The poor knowledge of the state of the atmosphere is the limiting factor on predicting or inverting the path of signals from source to sensor. Improving atmospheric information used, by outside the box technologies (e.g. profiling light detection and ranging (LIDAR) at stations or other important locations) to improve ATM outcomes for the IDC.

From an ATM point of view, next to mesoscale resolution developments to incorporate complex terrain and high resolution weather data, ATM - already a steady operational tool providing useful information, can benefit tremendously from the potential of ensemble meteorological data as currently provided by weather forecast centres, e.g. work to define the level of confidence in the results (uncertainty quantification).

IMS station technology, ATM simulation/ numerical weather prediction technology and knowledge of background emitters are changing. As such, we should make use of opportunities to exercise and perhaps modify our approach. ATM challenge(s), NDC Preparedness Exercises and signal screening exercises present such opportunities. Provisions of datasets for use by NDCs and others to develop their radionuclide) event analysis capabilities (detection, screening, association and reconstruction) are crucial. One of the key challenges for today's verification community is the interpretation of the IMS data available, and through the development of systematic analysis pipelines, how signals from the IMS can be combined into a single event (an 'event-builder'). Radionuclide detections require screening (or 'flagging') before they can be assessed for possible association with another detection(s). Adding relevant non-detections, either at the same location or different ones. can improve the ability to accurately locate a radionuclide release.

3.2.4 Potential of Additional Monitoring and OSI Technologies

Pa2.4 **Panel Discussion on Technologies**
Moderator: Florence Rivière-Bourhis, *Former CTBTO Preparatory Commission*
Panellists: Constantino Listowski, *Commissariat à l'énergie atomique et aux* énergies *alternatives, France*
Jennifer Stevanovic, *Atomic Weapons Establishment, United Kingdom*
Johannes Hotz, *Leica Geosystems, Switzerland*
Laurel Sinclair, *Canadian Hazards Information Service, Natural Resources Canada, Canada*
Michaela Frei, *Federal Institute for Geosciences and Natural Resources, Germany*



Pa2.4: Displacement maps based on radar data of Sentinel / Radarsat/ ALOS-2 space-based sensors and change detection map based on the space sensor Pleiades (optical, right bottom).

Laurel Sinclair explained novel approaches for high sensitivity gamma imaging for OSI. The current standard is to use large volume gamma detectors mounted on vehicles or airborne platforms to provide a wide area search for radioactive material. However, incomplete coverage can result in limited or misleading information. The ground based and mobile high sensitivity gamma imager can map radioactivity tomographically. These imaging spectrometers use multiple viewpoints and can associate radioactivity with visible objects.

Jennifer Stevanovic talked about the potential of novel seismic methods for OSI. She provided examples of time-lapse seismic monitoring detection. This has the capability of detecting dynamic phenomena associated with an

underground nuclear explosion using multiple seismic surveys and machine learning. Potential imaging sources are a thermal signature, a pressure signature, or ground water mounding and flow.

Michaela Frei gave a brief introduction on the use of space borne optical and radar remote sensing data to characterize the tests carried out by the Democratic People's Republic of Korea. She explained how satellite remote sensing can be applied towards a ground truth of nuclear tests. She demonstrated using examples from the Democratic People's Republic of Korea nuclear tests in 2016/2017 using displacement maps based on radar data of Sentinel, Radarsat and ALOS-2 as well as a change detection map based on the optical sensor of Pleiades highlighting the landslides following the 2017 test.

Constantino Listowski provided an up to date discussion about infrasound LIDAR research. Infrasound propagation is driven by middle atmospheric winds and temperature. It is challenging to account for the propagation medium. The middle atmospheric dynamics are not well resolved by numerical weather prediction models. Lidar observations can provide amplitudes and periods of waves in the middle atmosphere. This information can lead to better localization and characterization of infrasound sources.

Johannes Hotz has developed ground based autonomous platforms with sensors that operate in potentially hazardous environments. He demonstrated how autonomy, robotics and LIDAR technologies can help to improve OSIs and monitor nuclear sites. He showed examples of robots that move either teleoperated or autonomously into inaccessible locations and scan the area while it moves through. Sensor data are fused, e.g. a LIDAR and gamma radiation imager, and as a result, a real time 3-D gamma radiation image and a dose plan can be created.

3.2.5 Preparations for the Next OSI Field Exercise

Pa2.5 **Panel Discussion on OSI Field Exercise**
Moderator: Gustavo Haquin Gerade, *Israel Atomic Energy Commission, Israel*
Panellists: Alejandra Martinez, *Ensenada Center for Scientific Research and Higher Education, Mexico*
Gordon MacLeod, *Los Alamos National Laboratory, USA*
Malcolm Coxhead, *CTBTO Preparatory Commission*
Nortin Titus, *Geological Survey of Namibia, Namibia*
Peter Sankey, *Atomic Weapons Establishment, United Kingdom*

The panellists shared their views on the purpose and role of OSI exercises in the development of OSI capabilities prior to the Treaty entering into force.

Gordon Macleod commenced by discussing the ambassador Starr report published in 2003. Based on this, he took a retrospective look at the integrated field exercises (IFE) of 2008 and 2014 and commented on the technologies exercised at those events, noting that several additional techniques were exercised in 2014. Going forward, he expected additional techniques to be exercised at the next IFE in 2025. Along with equipment development, he highlighted the importance of the development of a system to support search logic and the visualization of inspection information, the Geospatial Information Management for OSI (GIMO) system. He stressed the importance of exercising in realistic environments with relevant signatures to provide an engaging setting to stimulate surrogate inspectors.

Malcolm Coxhead built on this historical background by looking forward to the OSI build-up exercise in 2024 and the IFE in 2025. He emphasized the need to consider exercising in more challenging environments and to go beyond shallow subsurface site characterization. Without divulging information related to the IFE25 scenario, he identified the following issues that require exercising in the future: a scenario with a horizontal emplacement; the presence of the

requesting State Party's observer; testing of the draft OSI Operational Manual text based on standing arrangements and multiple bases of operation.

Peter Sankey started his address by highlighting the importance of training accreditation and regular training to build mutual trust. In this respect, he stressed the importance of field training but also maximizing the potential of virtual training. Accreditation of personnel and equipment, he stated, is particularly important if the result of their activities/use results in a legal challenge. Like previous speakers, he emphasized the need to test capabilities and capacity in realistic and more challenging environments. He concluded by mentioning artificial intelligence and the impact it may have on an OSI.

Alejandra Martinez spoke about her experience as a surrogate inspector. Her comments were directed at a broad audience but specifically reached out to young professional females from developing countries and encouraged them to get involved in OSI training. Prior to the third OSI inspector training programme, she described herself as being within her comfort zone professionally. Following her introduction to OSI during a regional introductory course, she spoke about being challenged on a range of different themes including the application of techniques, communication and leadership She has learnt, during OSI training events, how to communicate more effectively in order to achieve better outcomes. She described that she is now able to impart OSI knowledge as was highlighted in her role as a facilitator during a regional introductory course in Thailand in 2023.

Norton Titus continued on the same theme by focusing on his experience during the third OSI inspector training programme. He described the collegiate spirit amongst the trainees and their passion for learning and for performing their tasks. The training programme had served to highlight their discipline, commitment and dedication to the OSI regime. He stressed the professional and personal training aspect of the programme including specialist training as a negotiator. Titus commented on the effective training provided by the PTS that had facilitated the development of an effective roster of inspectors. Finally, he spoke about the way that he has applied knowledge and experience gained during the training programme within his home institution.

3.2.6 Enabling Regional Capacities and National Data Centre Support with Training and Technical Assistance

Pa2.6 **Panel Discussion on Regional Capacities**

Moderator: Paola García Peña, *Comisión Chilena de Energía Nuclear, Chile*

Panellists: Daniela Veronica Ghica, *National Institute for Earth Physics, Romania*

Keyla Carolina Ramirez Loaiza, *Fundacion Venezolana de Investigaciones Sismologicas, Venezuela*

Marleine Brax, *National Center for Geophysics, Lebanon*

Mako Sitali, *Ministry of Mines and Energy, Geological Survey of Namibia, Namibia*

The NDCs are crucial for advising their National Authorities on nuclear explosion monitoring, and in many cases, they play an important role as station operators and in transmitting IMS data to the PTS in Vienna. This panel discussed the synergy between the PTS and regional experts. The PTS provides technical assistance and training for building the required national and regional capacity. NDCs can go beyond the capability of the IMS because they have access to regional network data that are useful for enhancing the monitoring capabilities. With their expertise, the NDCs provide feedback to enhance IDC products and services. The quality and effectiveness of Treaty monitoring benefit from this international cooperation.

3.2.7 NextGen for the CTBT: Making the Youth Voices Heard

I2.7-919 **Invited Talk on Empowering the Youth as Torch Bearers for Science and Security**
Invited Speaker: Adelakun Abel Ayoko, *Former CTBTO Preparatory Commission Chair*

Ambassador Abel Ayoko underscored the remarkable dynamism and boundless creativity of young people, surpassing even the limits of imagination. Addressing the audience at SnT2023, he urged them to lend their support, highlighting that when youth are included in discussions, they introduce novel perspectives, innovative concepts and distinct approaches to problem solving. He emphasized the need to guide and mentor young individuals in stepping up to drive the implementation of the Treaty. He pointed out that as current members of the CYG they take on more significant responsibilities in their respective professional pursuits, they are destined to emerge as the future global leaders.

Pa2.7 **Panel Discussion on Next Generation**
Moderator: Sitara Noor, *Belfer Centre, Harvard University, USA*
Panellists: Ahmed Elsabagh, *Major Group for Children and Youth at the United Nations*
Alice Saltini, *European Leadership Network, United Kingdom*
Magdalene Wangui Wanyaga, *SandRose Ltd., Kenya*
Maria Chepurina, *Former CTBTO Preparatory Commission*

The empowerment of the next generation of experts capable of supporting the mission of the CTBTO, both politically and technically, and advancing the universalization and entry into force of the CTBT is a cross-cutting objective. The panellists highlighted the achievements of CTBTO initiatives focused on supporting youth, shared best practices of next generation engagement format, and discussed forward looking actions. Moreover, it served to raise awareness among experts, diplomats and other United Nations' bodies about the role of the young professionals in supporting the universalization and entry into force of the CTBT.

During the first part the panellists described their experience as members of CYG and the YPN. Alice Saltini mentioned that the short term impact of CYG is the advocacy for the CTBT through its active membership showcasing support for the Treaty among the next generation. Meanwhile, as a long term impact, she mentioned the broad network of members and their role in targeting policy dialogues in Annex 2 States.

Maggie Wanyaga mentioned that YPN has established a solid pool of competent technical experts supportive of the CTBT and interested in further developing its verification technologies. YPN highlights the unique role of the CTBTO as a science and technology driven organization, paving the way for greater diversity and gender balance.

During the second part the panellists defined strategic next steps and innovative activities that could be adopted by the CYG to further support the CTBTO's strategic priorities of Treaty universalization and entry into force, as well as technical modernization. Panellists encouraged the CYG members to build connections with youth groups that have well established policy impact and that share the same objectives in the field of disarmament and non-proliferation. The example of the Younger Generation Leaders Network on Euro-Atlantic Security was given and its involvement with the Treaty on the Non-Proliferation of Nuclear Weapons. In addition to foster connections or launch educational activities led by CYG members specifically targeted at fostering dialogue on the CTBT in Non-Annex 2 States. Maggie Wanyaga suggested that the YPN should promote younger experts through programmes such as the YPN Exchange Program.

Maria Chepurina, in her private capacity, suggested that the CYG should encourage more interdisciplinary cooperation and more engagement with initiatives that focus on the

United Nations Sustainable Development Goals (SDGs), climate change, etc. She also mentioned a number of events in which the CYG could participate, such as: the High-Level Political Forum on Sustainable Development, the SDG Summit, the International Conference on Science and Technology and the Summit of the Future 2024.

3.2.8 Operating the IMS in the Framework of the International System of Units

I2.8-912 **Invited Talk on International Measurement Equivalence – a Fundamental Backbone for IMS**
Invited Speaker: Takashi Usuda, *National Institute of Advanced Industrial Science and Technology, Japan*

Drawing upon his extensive history of holding key roles within the international acoustic, ultrasound and vibration metrology community, Takashi Usuda was able to provide an authoritative description of the framework and mechanisms that form the basis of all trustworthy measurements, regardless of the technological field. He elucidated this framework, overseen by the Bureau of International Weights and Measures behind the scenes, and often unnoticed by the majority, encompassing the fundamental structure of international metrology and the tools essential for attaining worldwide uniformity in measurements. He provided a detailed insight into the mechanism and the rules governing international key comparisons, and the dissemination of their results via regional structures and the process of 'linking'.

This procedure provides the technical basis for the mutual acceptance of measurement results based on the proven equivalence. It is also a generic, versatile tool to monitor the stability and quality of measurement systems. Finally, Mr Usuda illustrated the current situation in acoustic, hydroacoustic and vibration metrology from the perspective of the International System of Units (SI) and emphasized the willingness of the International Committee for Weights and Measures, which is the custodian of the metric system or the SI, to further collaborate with the PTS to provide the link between the SI and the IMS. This ongoing collaboration demonstrates the trustworthiness and credibility of IMS data by ensuring consistency in IMS measurements and equivalent in data produced across the IMS network.

Pa2.8 **Panel Discussion on Metrology**
Moderator: Richard Barham, *Acoustic Sensor Networks Limited, United Kingdom*
Panellists: Franck Larsonnier, *Commissariat à l'énergie atomique et aux énergies alternatives, France*
Lind Gee, *U.S. Geological Survey, USA*
Svetlana Nikolova, *Geoscience Australia, Australia*
Thomas Bruns, *Physikalisch-Technische Bundesanstalt, Germany*
Takashi Usuda, *National Institute of Advanced Industrial Science and Technology, Japan*
Current operational challenges in the calibration of IMS seismic and hydroacoustic T phase stations include equipment compatibility, complex and infrequent tasks performed by station operators and PTS officers, resource intensive planning, limitations of the underlying electrical calibration principle (neglects ground coupling, impacts data availability and mission capability), lack of measurement traceability and significant engineering requirements.

IMS seismic operations can leverage established best practices in national networks and draw from recent successes in quality assurance for IMS infrasound measurements. This involves adopting a similar approach tailored to address specific technical and logistical challenges, which should not be underestimated. Operational aspects are vitally important and sustainment is becoming an increasingly significant key topic. Station operators should ideally be involved in such matters and a collaboration platform to facilitate discussions and knowledge transfer would be beneficial, especially in the context of station upgrade processes.

Better articulation and assessment of seismic system performance requirements would be helpful in managing the diversity of legacy equipment and in defining future performance requirements for equipment and systems deployed in the IMS network. This would apply to digitizer and sensor specifications, to type approval to maximize equipment compatibility and it would lead to revised and improved calibration processes.

The benefits of further collaboration with the metrology community and linking IMS monitoring within the SI include: greater take-up of measurement traceability, mutual acceptance of global calibration capability, better understanding of uncertainty in measured quantities (e.g. seismic amplitude and phase), better characterization of sensors' susceptibility to the environment and installation conditions, enhanced interoperability stemming from performance based specifications for equipment and common operating procedures. Such benefits impact all stages from equipment specification and type approval, through to on-site calibration.

Implementation of the strategy for infrasound is ongoing with several elements still to be implemented, including dissemination and training, roll-out of systems and formalization of the quality framework. The wider seismic–acoustic monitoring community can also benefit from the anticipated improvements driven from within the IMS, with similar outcomes to those noted above, thereby adding value to the investment in the IMS through extending take-up and spreading the impact to a broader range of applications.

3.2.9 CTBTO/UNODA Joint Panel on Leveraging Advances in SnT for Multilateral Verification Purposes - Possibilities and Challenges

Pa2.9 **Joint Panel CTBTO/UNODA**

Moderator: Fanny Cossette Tonos Paniagua, *Former CTBTO Preparatory Commission*

Panellists: Mayra Ameneiros, *Centre for Science and Security Studies, King's College London, United Kingdom*

Michelle Grobbelaar, *Council for Geoscience, South Africa*

Oleg Rozhkov, *CTBTO Preparatory Commission*

Peter Hotchkiss, *Organisation for the Prohibition of Chemical Weapons, The Netherlands*

On the last day of the conference, the CTBTO hosted this panel in collaboration with the United Nations Office for Disarmament Affairs (UNODA). The five day programme impressively demonstrated how technological advances provide opportunities to improve the effectiveness of the CTBTO verification system, support national needs and promote civil and scientific applications. Prior to the closure of the conference, this panel is opening the horizon. The CTBT is an important pillar in the broader context of international efforts to prevent and monitor proliferation and threads from all kinds of weapons of mass destruction: nuclear, biological, and chemical. In that context, this panel explored what lessons may be learned from technology-based verification across the various regimes.

The panellists started by giving a brief introduction to the multilateral control regimes under consideration here and the importance of science and technology advances in each of them. There are similarities and differences between the different control regimes. For the Chemical Weapons Convention, a main challenge is to keep abreast with the advances in the industry and new chemicals being introduced into the market. For the Biological Weapons Convention, the main challenge is that no formal verification system is in place. The common experience is that advances in science and technology can drive progress in advising evidence based policies and solutions for verification and impact confidence building within the community.

The second question was about the different mechanisms for monitoring relevant technological advances that are in place within the CTBT and other weapons of mass destruction regimes and how any initiatives have served or may serve to drive

policy making. The main aim of science and technology monitoring mechanisms is to identify innovative solutions that can be leveraged for advances in verification technologies and methodologies. The panellists explained the role and contribution of scientific and technological institutions, civil society and industry towards advances in verification capabilities. They explained the institutions and mechanisms to connect the verification body with stakeholders for the transfer of relevant knowledge.

The third question addressed by the panellists was to compare the different control regimes and assess what achievements might be transferred from one control regime to another. The discussion referred to best practices and the role of certain stakeholders like civil society, industry and scientific networks.

There is a lot of value in continuing this discussion and further promoting exchanges of experience among the various multilateral verification regimes for preventing the proliferation of weapons of mass destruction. While the treaties and verification mechanisms underpinning these various regimes are very distinct, science and technology developments remain a common denominator for achieving advances in multilateral verification frameworks and maintaining confidence in the system. There are a lot of opportunities for synergies and lessons learned across the various regimes. Established structures like the scientific advisory group of the Organisation for the Prohibition of Chemical Weapons provides a good example of a mechanism that could be used to leverage advances in science and technology. The involvement of civil society and industry is also key for successfully leveraging advances in science and technology to enhance effective verification and to reflecting scientific findings in policy actions. The SnT conference series sets a precedent for an open process of gathering the expert community together to exchange information on the latest advances in science and technology and how these can be made fruitful for the IMS provisional operation and the preparation for OSI readiness.

3.2.10 Regional Capacity Building in French Speaking Countries in Africa

Pa2.10 **Renforcement des capacités régionales en Afrique francophone**

Moderator: Gerard Rambolamanana, *CTBTO Preparatory Commission*

Panellists: Abdour Wahab Djibo Maïga, *Haute Autorité Nigérienne à l'Energie Atomique, Niger*
Komenan Benjamin Kouassi, *Station Geophysique de Lamto, Côte d'Ivoire*
Mohamed Kasmi, *Centre National pour la Recherche Scientifique et Technique. Morocco*
Rakotondraibe Tsiriandrimanana, *Institute and Observatory of Geophysics of Antananarivo, Madagascar*

In this panel there were short presentations by the participants from Madagascar, Morocco, Niger and Côte d'Ivoire, followed by questions from the moderator and the audience. The panellists presented the challenges encountered during field operations for the installation and maintenance of IMS stations, and also for their own network. The difficulties can differ from one region to another, from one country to another. The panellists highlighted common difficulties and also provided common solutions. The main conclusions of the panel can be summarized in three points: (1) The challenges and solutions; security at the site level, the transport of materials to the sites, digital connectivity and finally energy, are the main challenges common to all. A continuous sensitization approach at the level of all managers, from the locality where the stations will be installed, or where the stations are already installed, up to a certain level of leaders, is fundamental. In addition, the use of new IT technology for site monitoring such as surveillance cameras, alerts, etc. is important. (2) The panellists proposed other solutions such as possible synergies between the NDCs of the French speaking region to strengthen the capacities of the managers, station operators and personnel of the NDCs to develop IMS data analysis capabilities combined with local network data. (3) The panellists will continue to have exchanges to concretize the points mentioned during the exchanges.

3.2.11 The Role of CTBT IMS Data to Support Disaster Risk Mitigation

Pa2.11 **El papel de los datos del SIV del TCPE para apoyar la mitigación del riesgo de desastres**

Moderator: Xyoli Pérez-Campos, *CTBTO Preparatory Commission*

Panellists: Mariana Patricia Jácome Paz, *Instituto de Geofisica, Universidad Nacional Autónoma de Mexico, Mexico*

Federico Guendel Umana, *Former Observatorio Vulcanologico y Sismologico de Costa Rica, Costa Rica*

Sergio Barrientos, *University of Chile, Chile*

Juan V. Cantavella Nadal, *Instituto Geografico Nacional, Spain*

This panel consisted of brief presentations by the participants from Spain, Costa Rica, Chile, the Dominican Republic and Mexico, and was followed by questions by the moderator and the audience present in the conference room and online. The panellists explained how the data from the IMS contributes to tsunami early warning in Spain, Central America and Chile and talked about how the use of IMS seismic data through the Dominican Republic NDC contributes to the national seismic monitoring. Also mentioned was how the people from the NDC benefit from the capacity building and training offered by the PTS and finally the panellists presented the status of volcano monitoring in Latin America, a region that is recognized as not having used the infrasound data from the IMS but that has benefited from the advances in the technology thanks to the IMS. The main conclusions of the panel can be summarized as follows:

Data from an additional station can greatly contribute to purposes such as tsunami warning. In tsunami prone countries, the seismic network is mainly located on one side of the tsunamigenic seismic source. Even though there are a large number of stations on a limited range of azimuths, the source characterization would have a large uncertainty. Adding one station in a complementary direction improves the source characterization reducing the uncertainty of the tsunami warning. In other words, adding to the analysis the IMS data, helps break down the political boundaries that limit the national networks.

The use of the IMS data has fostered regional collaboration and scientific collaboration with the CTBTO. The national and regional technical community has not only benefited from the data but also from the capacity building. Given the rotation of the personnel in the NDCs, continuous training is required. However, if this training is not offered in the regional language, in this case Spanish, some people would be left out. This highlighted the relevance of multilingualism and having regional training in the language of the region, with training material in the regional language.

Natural hazard risk reduction is another potential application for the use of IMS. CTBTO has fostered and pushed forward methodologies to analyse the data from the four technologies that constitute the IMS network. In a way, CTBTO has become the facilitator. New ways of collaboration and new uses of the IMS data that contribute to risk reduction can be explored in the future.

Despite the vast contribution of the Latin American and the Caribbean region to the IMS network, including expertise and potential, the region is currently underrepresented on the staff of the PTS.

3.2.12 Mutual Benefits Between Arabic Speaking Countries and the CTBTO

Pa2.12 **المنافع المتبادلة بين البلدان الناطقة باللغة العربية ومنظمة معاهدة الحظر الشامل للتجارب النووية**

Moderator: Abdelouaheb Agrebi, *Former CTBTO Preparatory Commission*

Panellists: Daw Saad Mosbah Khalefa, *Arab Atomic Energy Agency, Tunisia*

Mohamed Nabil Mohamed ElGabry, *National Research Institute of Astronomy and Geophysics, Egypt*

Mufreh Al-Rashidi, *Kuwait Institute for Scientific Research, Kuwait*

Shimaa Elkhouly, *National Research Institute of*

Astronomy and Geophysics, Egypt
Tawfiq Alyazjeen, *Jordan Atomic Energy Commission, Jordan*
Yasameen Hameed Shamkhi, *Iraqi National Monitoring Authority, Iraq*

This panel discussed the mutual benefits of cooperation between the CTBTO and Arabic speaking countries. Experts from Egypt, Jordan, Iraq, Kuwait and Libya, engaged in the operation of IMS stations and/or working at their respective NDCs, summarized the contributions from their countries and the PTS.
Contributions from the Arabic speaking countries include: hosting the IMS stations and operating them efficiently; carrying out maintenance of stations and high quality transmission of data to the IDC; hosting various training courses co-organized with the PTS and providing suitable venues and facilities for all types of training; hosting IFE14, the largest OSI exercise in the history of the PTS, and contributing to various expert groups councils and providing the necessary scientific expertise to the organization.

Contributions from the PTS to Arabic speaking countries include: providing IMS data and IDC products to their NDCs; contributing to the establishment of their NDCs by providing capacity building equipment providing data analysis applications for NDCs in Arabic speaking countries; involving NDC staff, IMS station operators and virtual inspectors in various training courses organized by the PTS; conducting the first NDC training for Arabic speaking NDCs and providing the CTBTO Annual Report in Arabic.

The panel recommendations from the dialogue session are listed below:

- Activating an expert exchange programme between the organization and Arabic speaking countries.
- Regularly providing training courses in Arabic on waveform and radionuclide technologies.
- NDCs from Arabic speaking countries can provide the necessary experts and trainers to assist the organization in conducting training in various specialties in Arabic.
- Providing Arabic language support on the organization's official web site.
- Establishing an Arabic forum where NDC staff and station operators can exchange knowledge and discuss scientific events and verification regime-related ideas.
- Increasing support for Arabic speakers' participation in OSI exercises.
- Strengthening the coordination with Arabic speaking staff in CTBTO Divisions that provide training to States Signatories, such as OSI and the IDC.
- Updating the status of NDCs from Arabic speaking countries in the organization's records and taking into consideration the individual needs of each NDC owing to the varying technologies used.
- Providing advanced technical training in various technologies used by the organization.
- Providing digital lessons in Arabic in the organization's four technologies and OSI.
- Providing operating guidelines for NDC software in Arabic.
- Reactivating the participation of NDC staff in long term training courses (3 or 6 months).
- Focusing on regional cooperation between NDCs in Arabic speaking countries and regional entities with similar expertise, such as the Arab Atomic Energy Agency.
- Conducting trainings and workshops in Arabic speaking countries to further reinforce the participation of women.

3.2.13 Introduction of the Synergies Between Professional Societies and the CTBTO

Pa2.13 **Keynotes by Professional Societies**
Moderator: Sanam Shantyaei, *CTBTO Preparatory Commission*
Panellists: Kathy Whaler, *University of Edinburgh, United Kingdom*
Margaret Hellweg, *Seismological Society of America, USA*
Massimo Pellegrino, *Institute of Electrical and Electronic Engineers, USA*
Michelle Grobbelaar, *Council for Geoscience, South Africa*
Oladoyin Odubanjo, *The Nigerian Academy of Science, Nigeria*
Silvia Blanc, *Argentinian Navy Research Office, Argentina*
Atalay Ayele Wondem, *Addis Ababa University, Ethiopia*
Marino Protti Quesada, *Observatorio Vulcanologico y Sismologico de Costa Rica, Costa Rica*

The panel explored the intersection of science, technology and CTBT related activities, highlighting their contributions to global peace and security. The speakers also highlighted the strong connections between the professional societies that were represented on the stage.

Additionally, they encouraged the audience to engage with their communities and associations as such collaboration would facilitate the exchange of knowledge and insights, especially from regions that are underrepresented. One panellist called this a "beneficial partnership" that can serve as a valuable bridge between these communities and policymakers.

The panellists also called on the audience to connect with them if they have fresh and innovative ideas. Other topics that were discussed included the idea that cooperation can significantly improve our grasp of science and technology. Additionally, there was a strong emphasis on increasing youth participation, recognizing them as the driving force. Notable reference was made to initiatives spearheaded by the CTBTO, including CYG and the CTBTO Mentoring Programme. Lastly, speakers from professional societies addressed the importance of providing training, scholarships and other support to help the next generation of experts develop into future leaders.

3.2.14 Introduction of Professional Networks Promoting Female and Young Experts in STEM and Cooperation with CTBTO

Pa2.14 **Keynotes by Professional Networks**
Moderator: Sanam Shantyaei, *CTBTO Preparatory Commission*
Panellists: Anne Strømmen Lycke, *Norwegian Seismic Array, Norway*
Marius Jano, *CTBTO Preparatory Commission*
Gabi Voigt, *Women in Nuclear Global, United Kingdom*
Rengin Gok, *U.S. Department of Energy, National Nuclear Security Administration, USA*
During the panel discussion, experts shared their personal and professional experiences. They offered valuable tips to empower women and young professionals in STEM fields, encouraging them to not only seize opportunities, but also to engage more actively, and collaborate effectively with the CTBTO.

The discussion highlighted several key initiatives spearheaded by the CTBTO, including the CYG, the CTBTO Mentoring Programme and YPN - established in partnership with the Norwegian Seismic Array (NORSAR).
At the core of the conversation was a clear message: the importance of discovering one's passions and interests and the consensus was clear – inclusivity is paramount. This principle is particularly relevant for women and young talents who have traditionally been marginalized in the STEM field.

Moreover, an audience member underscored an additional, yet equally vital aspect – the inclusion of individuals with disabilities. This message resonated strongly, emerging as one of the prevailing themes throughout the panel.

3.3. Invited Talks

3.3.1 Standardization, Conformity Assessment and Certification

I4.1-880 **Standardization**

Invited Speaker: Ravi Subramaniam, *Institute of Electrical and Electronic Engineers, USA*

Ravi Subramaniam explained what is important to know about standardization, conformity assessment and certification and what the Institute of Electrical and Electronic Engineers (IEEE) is doing in these fields. The IEEE Standards Association is a huge subnetwork of the IEEE with more than 400 corporate and 8500 individual members spanning a broad spectrum of technologies. Standards development is an evolving process that involves different stakeholders. Conformity assessment is the process or processes that are used to demonstrate that a product or service meets specified requirements as set forth in standards, test plans, etc. The speaker introduced an example for certification. The IEEE Nuclear Standards Certification program was launched to ensure products and components utilized to build nuclear power plants meet requirements for harsh environments and seismic events. Manufacturers and equipment qualification test laboratories can apply to become IEEE recognized. Of special relevance for the CTBTO experts is the IEEE Sensors Advisory Committee, specifically the wireless technologies that enable a wide range of Internet of Things services. Mr Subramaniam explained the Trust, Identity, Privacy, Protection, Security and Safety (TIPPS) framework for evaluating the non-functional requirements of sensor networks. The IEEE Sensors Advisory Committee is a comprehensive initiative to address interoperability and cybersecurity concerns with utilization of the sensors of the Internet of Things. It is open to participants from industry, academia and consortia. It provides implementation recommendations for the adoption of open standards, protocols, interfaces, data exchanged and to define certification criteria.

The purpose of this talk was to offer a forum for discussion to identify possible areas of common interest between the IEEE standardization activities and the CTBT experts' community. Therefore, this introduction was followed by a dialogue with the audience.

The global integration of sensors into one IMS, ensuring interoperability of all technologies during an OSI, and the fusion of data from four different sensor technologies, have already been broad domains for standardization for several decades.

The CTBTO has recently shared the release of IDC FDSN Web Services for testing by the Global Communications Infrastructure connected NDCs. The International Federation of Digital Seismograph Networks (FDSN) is a global organization. Its membership is comprised of groups responsible for the installation and maintenance of seismographs either within their geographic borders or globally. The FDSN was instrumental in the development of a universal standard for distribution of broadband waveform data and related parametric information. The Standard for the Exchange of Earthquake Data (SEED) format is the result of that effort. The CTBTO uses its own data format known as IMS2.0. In addition, the CTBTO has adopted the MiniSEED format in the framework of capacity building for NDCs, specifically in the NDC in a box software package. This includes a conversion tool to convert IMS2.0 into the MiniSEED format. MiniSEED is the subset of the SEED standard that is used for time series data. The CTBTO is also cooperating with the International Association of Seismology and Physics of the Earth's Interior (IASPEI) Commission on Seismological Observation and Interpretation that is responsible for setting standards in observational seismology such as the New Manual of Seismological Observatory Practice, the IASPEI Seismic Format, the IASPEI Standard Seismic Phase List and the IASPEI Ground Truth List.

Based on this in depth experience and encouraged by this invited talk and discussion,

the CTBT experts may identify possible gaps and needs within the CTBT related science and technologies that may benefit from further standardization and certification. CTBT activities do not need to become IEEE recognized. A possible benefit could be implementation recommendations for procedures like station certification and system and software acceptance testing. The IEEE Standards Association stands ready and is well equipped to support such activities.

3.3.2 Cascading Multi-Segment Faults Triggered by Supershear Rupture During the 2023 South East Türkiye Earthquake Doublet: A Giant Jigsaw Puzzle Mobilized

I4.2-897 **Panel Discussion on Large Seismoacoustic Events**
Invited Speaker: Tuncay Taymaz, *Istanbul Technical University,* Türkiye

Two devastating earthquakes that took place nine hours apart occurred on 6 February 2023, the first one along the East Anatolian Fault (EAF) with moment magnitudes of Mw 7.9 and the second large earthquake with Mw 7.7 was located 90 km north of the first mainshock on the east-west trending Sürgü-Çardak Fault (SCF).

Mr Taymaz introduced the historical and scientific context of the earthquake doublet in the complex tectonic region of the Anatolian plate, which creates a giant jigsaw puzzle. The seismic activity of the Anatolian region has been carefully studied since it is prone to intense and frequent earthquakes. Seismic earth models based on full waveform inversion were recently developed to circumvent historically limited resources.

Mr Taymaz published a paper two years prior to the earthquake doublet highlighting that the region at the intersection of EAF and SCF had not experienced noteworthy seismic activity in the last couple of centuries. The kinematics of ruptures for the 2023 earthquake doublet was very intense and complex involving multi-scale cascading ruptures across segments of both faults, this specificity creates a hybrid fault context leading to the catastrophic earthquake sequence. Furthermore, Mr Taymaz emphasized that the doublet was followed by intense aftershock activity, which continued until the Mw 6.4 of 20 February, a few kilometres south east of the doublet on the EAF.

Mr Taymaz reported that the mainshock was initiated on a previously unmapped fault, the Nurdağı-Pazarcık segment, and it then transitioned to the EAF. This development leads to supershear bilateral ruptures and a subshear rupture on two adjacent fault segments. The dynamic stress of the initial rupture on the EAF segment accelerated the mechanism leading to the second earthquake with a westward rupture directivity along the SCF. The particular geometry and pre-stress level along the hybrid fault increased the intensity of the earthquake doublet, which contributed to amplifying the intense ground shaking observed by the global navigation satellite system and the pulse-like motions recorded by seismic instruments in the fault region. The level and characteristics of the ground shaking was reflected in the reported devastation observed by emergency and rescues teams on site in the following days and weeks.

The doublet earthquake sequence resulted in catastrophic human life and economic loss. It caused major damage to the infrastructure throughout south east Türkiye and north west Syria. Mr Taymaz reported on the lack of earthquake early warning capabilities in the region, which if in place would have contributed to limiting the earthquake impact.

3.3.3 The Experience of GeoSphere Austria in Multidisciplinary Partnerships: The Aristotle-eENHSP

I4.3-895 **Early Warning System**
Invited Speaker: María del Puy Papí Isaba, *GeoSphere Austria, Austria*

An example of multidisciplinary partnerships was shared by an early career scientist from

GeoSphere Austria which offered interesting insights into the CTBT community. The project considered is financed by the European Civil Protection and Humanitarian Aid Operation and is named ARISTOTLE-eENHSP - All Risk Integrated Trans-boundary Early-warning (ARISTOTLE)-enhanced European Natural Hazard Scientific Partnership (eENHSP). This partnership that was initiated in 2016 delivers real time multi-hazard expert and actionable advice on worldwide natural disasters to disaster management professionals from the European Emergency Response Coordination Centre.

ARISTOTLE is a framework composed of 24 national and international organizations across 15 European countries offering a flexible and scalable hazard related services system. Several of the partners are institutions active in the CTBT community. ARISTOTLE provides services on a large range of hazards, earthquakes, severe weather, flooding, forest fires, volcanoes and tsunamis, several of which generate signals also recorded by the IMS network.

The multidisciplinary partnership has long term objectives relevant for the advances of the civil and scientific applications of the IMS, which focuses on operational, research and cooperation components leading to emergency response, routine monitoring and scientific technical assistance facility. The consortium organizes and coordinates training activities relevant to the expertise it provides over a wide range of hazard concepts.

3.3.4 Examples of U.S. Transparency and Verification Supporting Nuclear Nonproliferation

I4.4-901 **Highlight talk**

Invited Speaker: Corey Hinderstein, *Deputy Administrator for Defense Nuclear Nonproliferation, National Nuclear Security Administration, U.S. Department of Energy, USA*

Corey Hinderstein's remarks reaffirmed that the United States of America (USA) supports the CTBT and is committed to work to achieve its entry into force, recognizing the significant challenges that lie ahead in reaching this goal. She explained that the USA continues to observe a moratorium on nuclear explosive testing and calls on all States possessing nuclear weapons to declare or maintain such a moratorium, and that the USA has no plans to conduct a nuclear explosive test.

She provided many examples of US support for the CTBT, including development of the next generation Xenon International noble gas analysis system for use in the IMS; IMS component testing; US funding for the maintenance, operation and improvement of its IMS stations; and support for the IDC through projects such as IDC re-engineering and the regional seismic travel time (RSTT) model. She also provided numerous examples of transparency related to activities at NNSA sites such as the Nevada National Security Site and the national laboratories. The USA shares significant information about its plans and operations and is open with the international community about its stockpile stewardship activities such as subcritical experiments and the recent fusion breakthrough, as well as non-proliferation related field experiments at the Nevada National Security Site.

She concluded by recognizing the importance of diversity and inclusion in non-proliferation and reiterating the US commitment to the CTBT and transparency into the operations of NNSA.

4. Oral and E-Poster Presentations

4. Oral and E-Poster Presentations

SnT2023 focused on five scientific themes:1. The Earth as a Complex System, 2. Events and Nuclear Test Sites, 3. Monitoring and On-Site Inspection Technologies and Techniques, 4. Sustainment of Networks, Performance Evaluation and Optimization, 5. CTBT in a Global Context. Several topics were identified under each theme. Authors were required to submit each of their abstracts under one of the topics. Oral and e-poster presentations were invited under each topic.

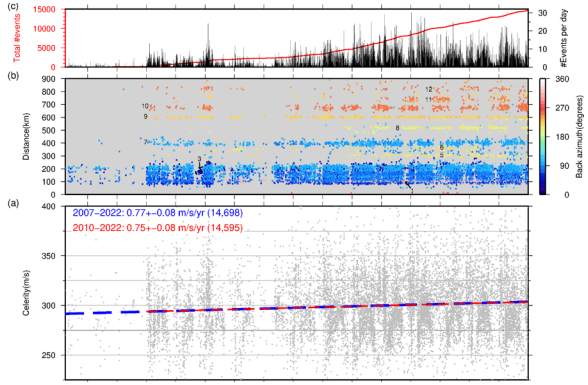
Theme 1: The Earth as a Complex System

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 global, regional and local 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 is put on 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. Yet another area is subsurface properties relevant to the detection of a nuclear explosion by geophysical, radionuclide or other methods during an OSI. However, relevant characteristics of the earth are not limited to those required for supporting current monitoring technologies. Novel methods of monitoring, including those using satellites or other remote sensing methods, also require characterization of specific properties of the earth's subsystems.

T1.1 The Atmospheric and its Dynamics

The session on the Atmosphere and its Dynamics consisted of five oral presentations and 20 e-posters. While the oral presentations covered mainly infrasound science and technologies (four out of five oral presentations) and one oral presentation on the dispersion of radionuclide tracers in the local atmosphere, the e-posters, on the other hand, showed a greater contribution from ATM developments. A summary, with highlights aiming at prospects for CTBT's verification technologies, is given blow:

A local scale atmospheric radionuclide tracer experiment (O1.1-849) demonstrated that the understanding of the impacts of near field air flow on the long range transport of radionuclides in the atmosphere after a release from an underground nuclear explosion requires improved modelling at the local scale. Experiments are designed to this aim, one of them entailing a variety of instruments including scanning LIDAR where the output can be used for high resolution meteorological model improvement, while another allows to improve short range models over complex terrain (P1.1-491). The consistency between ATM and IMS measurements benefits from multiscale and high resolution modelling when it comes to meteorological scales and

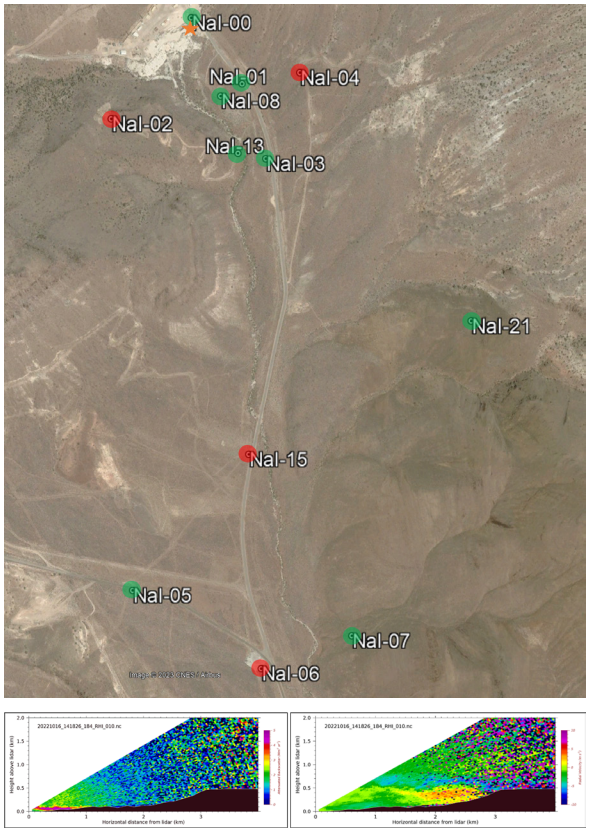


*O1.1-077: **Top** Detection trends over 15 years for IMS infrasound array IS46. **Middle** seismo-acoustic catalogue obtained for colocated IS46 and ZALV seismic aray, as seen from IS46. **Bottom** Celerity distribution over time with a significant positive trend and a recurring annual pattern.*

complex topography (P1.1-180 and P1.1-506) or changing atmospheric conditions (P1.1-158).

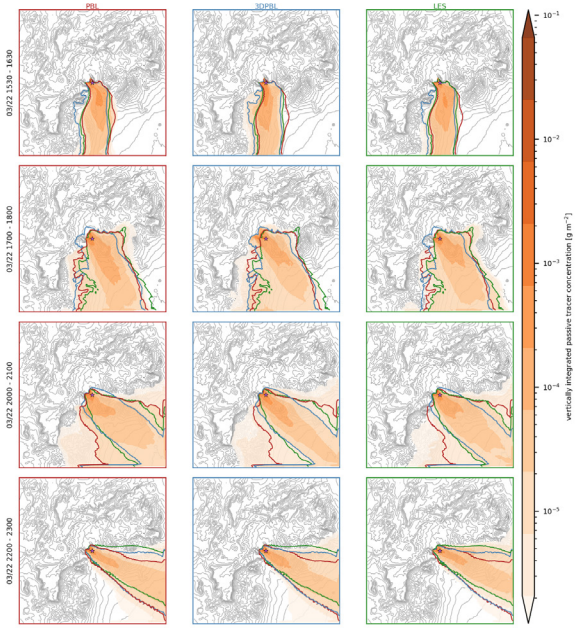
Rainfall patterns in tropical regions, observations of geomagnetic storms in Latin America, hurricanes in the Mediterranean Sea and atmospheric storms are some of the recent areas of research made possible using IMS infrasound data and IDC products (P1.1-405, P1.1-489 and P1.1-672). The detection trends at IMS infrasound stations over extended periods of time was discussed with the aim of finding indicators explaining seasonal variations (O1.1–442). For the rainfall and geomagnetic storms studies, infrasound detection bulletins are produced using the detection package DTK-PMCC (based on the Progressive Multi-Channel Correlation method) embedded in the NDC in a box package.

Emission data (e.g. from medical isotope production facilities or nuclear power plants and reactors) and observation data from IMS radionuclide stations can be of support when developing an operational modelling system. Uncertainties in meteorological models need to be taken into account, which remains challenging, however, it also presents benefits in an operational setting (P1.1-588). The topic of ATM is further explored in the context of validating models by using proxies such as studying the variability of beryllium-10 concentration (P1.1-581).



*O1.1-849: **Top** sensor locations where Xe-127 was detected (green) and not detected (red), superimposed on a Google Earth map of the experiment location. **Bottom** Vertical slice of attenuated backscatter LIDAR signal and calculated radial velocity measurements.*

Fifteen years of IMS seismic and infrasonic recordings contributed to climate studies by showing a seismic–acoustic analysis revealing long term changes in middle atmosphere temperature, enabling the study of climate change (O1.1-077). The results of the seismoacoustic analysis unravel temperature variability, both long term increases and decreases, from the surface based recordings. Understanding infrasound station detectability



P1.1-180: Time-averaged predicted (simulated) smoke plumes from a Δx = 40 m domain. Overlaid coloured contour lines at 10-5 g m2 from each simulation highlight noteworthy differences between the shape of predicted plumes, particularly when conditions are primarily locally forced. These simulated were compared with observations during the METEX21 campaign.

Wiersema, D. J., et al. (2023). Assessing turbulence and mixing parameterizations in the gray-zone of multiscale simulations over mountainous terrain during the METEX21 experiment. Front. Earth Sci. 11. doi:10.3389/feart.2023.1251180

is essential for network data processing and localization and identification of events (O1.1-205) at the local or regional range. Studying noise levels at infrasound stations is also vital to this aim, and it can also provide a proxy to identify appropriate areas for installation of infrasound stations (P1.1-805). A number of contributions also drew on the need to study and refine weather models at different scales, from small scale perturbations to long distance effects, which can assist in resolving gravity wave fields (P1.1-405 and P1.1-675). To this end, new observation platforms, beyond IMS infrasound stations, prove their usefulness (P1.1-541). On the topic of models, in the scientific community a widely used dispersion model, FLEXPART, was presented and evaluated as an upgrade was recently made available (P1.1-577, P1.1-749 and P1.1-502).

T1.2 The Solid Earth and its Structure

Session T1.2, the Solid Earth and its Structure aimed to cover new research on the earth's structure on different scales with a focus on how the data from IMS networks and stations could contribute to advances in geosciences to constrain the earth's interior. Moreover, how new findings in methodology, imaging and modelling of structures (i.e. in the scale of crust, mantle and core) could support the CTBTO event monitoring, production and inspection. The session included eight oral presentations and 45 e-posters. Highlights from oral and e-poster presentations are as follows:

The great importance of machine learning in seismic event detection and monitoring was shown and discussed in several presentations. As a result of the explosive growth of seismic stations worldwide, nowadays, one can record any signal from natural and anthropogenic events (O1.2-246). These recordings provide important input to be used to train detection systems for event detection and discrimination (e.g. explosions versus earthquakes). Also, it was shown that machine learning could improve seismic signal detection and travel time prediction (O1.2-179), hence the accuracy of automatically detected signals, created events and location accuracy (P1.2-139 and P1.2-586). Machine learning has the potential to replace conventional signal detection methods such as short term average over long term average, which could enhance the efficiency of monitoring and event detection at the CTBTO.

A number of presentations presented new seismic velocity models including P and S wave models for crustal and lithospheric scales. In addition to those who presented the results of traditional seismic tomography (P1.2-363, P1.2-433 and P1.2-874), there were presentations that used seismic ambient noise to image the crust and lithosphere (P1.2-213, P1.2-346 and P1.2-574). They illustrated the potential of using ambient noise to improve seismic velocity models, especially for regions with low or no seismicity. This highlights the need for advances to be made in small scale velocity models used in monitoring and data analysis at the CTBTO. In particular, the need for 3-D velocity models, which significantly improves event location accuracy.

Station installation and the monitoring network were discussed in several presentations. New advances and enhancements in local seismic networks to improve the capability of observations and event locations were shown (P1.2-101 and P1.2-447), as well as improving the location accuracy of example events (P1.2-157). Research results on station response files and spectra were also presented (P1.2-145). Furthermore, the installation of a combination of seismic and geodetic stations, a seismogeodetic network, in Mexico was presented and discussed (O1.2-800). This provides an opportunity not only to monitor crustal and lithospheric deformation but also to improve early warning systems, in this case, tsunami early warning. This type of observation network could also reduce uncertainties in different early warning systems, such as monitoring volcanic activities.

The RSTT model plays an important role in refining and improving seismic regional

travel time estimation and automatic phase picking. Proper data integration provides a great input to obtain well modelled RSTT in various regions (P1.2-437). Such data could be gathered from earthquakes, mine blasts and active seismic experiments. In addition, the performance of the RSTT model was assessed and discussed in relocating earthquakes in the Hangay region in Mongolia (O1.2-084). The advantages of implementing the RSTT models for better location accuracy were also shown (P1.2-101).

T1.3 The Oceans and Their Properties

Topic T1.3 comprised 15 contributions, including 3 orals, covering a wide range of hydroacoustic topics, such as long-range acoustic propagation and 3-D modelling, T waves generation and detection, tsunami and underwater volcanic activity data analysis, ocean noise level patterns, Arctic Ocean acoustic modelling, automated signal processing approaches, etc.

The oral session had actively involved participants, both online and in person. Three topics were discussed: (a) The analysis of signals generated by highly directional sources such as airguns, highlighting the advantage of 3-D versus 2-D modelling in capturing the effects of bathymetric features on long range acoustic propagation. This work was supported by comparisons between modelled and CTBTO acquired data (O1.3-536). (b) The wide breadth of CTBTO data applications was demonstrated through the analysis of T waves generated from earthquakes in the Kermadec Islands area. The analysis of data at IMS hydrophone stations revealed significant temporal and directional discrepancies in the arrivals of T phases triggered by Kermadec earthquakes, indicating the conversion of seismic to acoustic waves far from the earthquake epicentre in an area of prominent underwater features. (c) The development of an automatic acoustic signal processing algorithm to scrutinize T waves to infer the location and origin time of the underwater seismic event that generated them. The ongoing development of this algorithm is tested using hydroacoustic data recorded at IMS hydrophone stations (O1.3-579).

Presenters and participants praised the high quality and value of the CTBTO data, not only for their primary purpose, which is the monitoring of the oceans for signs of nuclear explosions, but also for their contribution to civil and scientific applications (P1.3-566 and P1.3-802). CTBTO was commended for making such data accessible to the scientific community through the virtual Data Exploitation Centre (vDEC) platform for multidisciplinary studies regarding the oceanic environment, tsunami warning and natural hazard reduction (P1.3-299). The audience expressed appreciation for CTBTO outreach activities, such as the SnT conference series and the international hydroacoustics workshops, to further discussions on the status and opportunities associated with the data acquired by the IMS.

Throughout the scientific discussions during the session, it became apparent that 3-D long range propagation hydroacoustic models represent a significant improvement in comparison to the capability and fidelity of the mainstream 2-D models (P1.3-515, P1.3-534 and P1.3-858). The main reason is that 3-D models allow horizontal diffraction, refraction and reflection around obstacles, or those caused by horizontal variations in oceanographic features such as currents or eddies. The 3-D models are available in a variety of formulations that have the potential of addressing the different needs of hydroacoustic signal analysis: estimation of blockage tables, travel time and reflections from bathymetric and/or oceanographic features. One recommendation is to incorporate these techniques into the IDC automatic processing software.

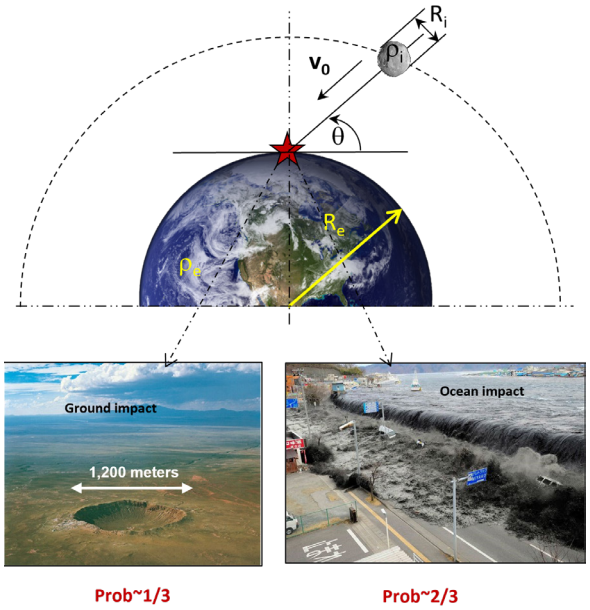
Moreover, 3-D modelling may improve our understanding of the complex arrival characteristics of T waves where the conversion from seismic to acoustic signals takes place in a bathymetric environment with prominent features and discontinuities, e.g. seamounts, that may act as secondary sources far away

from the epicentre of the original seismic event (P1.3-552). Understanding such sound propagation mechanisms has the potential to improve source localization and back azimuth estimates.

T1.4 Multidisciplinary Studies of the Earth's Subsystems

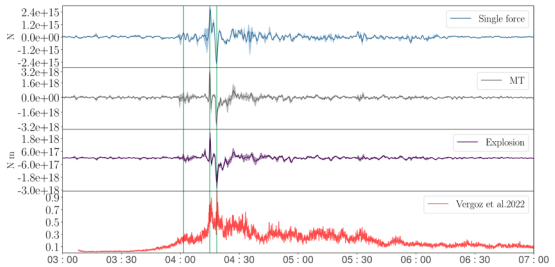
The session on Multidiscipline Studies of the Earth's Subsystems included four oral presentations and 11 e-posters that covered a wide range of multi-phenomenon studies often taking place at the interface between earth, the oceans and the atmosphere and demonstrating advances in the capability of fusion between waveform technologies.

The 2022 Hunga eruption attracted global attention as it produced an unprecedented explosion in modern times. Studies of the eruption were highlighted throughout the conference at the large seismoacoustic event session with a highlight talk and a panel discussion of experts. It was also broadly covered during this session with three oral presentations and six e-posters. Presentations focused on the atmospheric propagation of infrasound acoustic gravity waves that circumnavigated the earth at least four times over nearly six days, this was shown in particular in O1.4-514 (which received the award for best oral presentation) and P1.4-796, and there were attempts to model the



P1.4-272: Quantitative hazard assessment of Near-Earth Objects (NEOs) impact on Earth (solid or water).

infrasound signals propagating over large distances in O1.4-875 (pre-recorded). In P1.4-472, another aspect that attracted the attention of researchers was how the Hunga eruption compared with the 1883 Krakatoa (Indonesia) eruptions, or more precisely, how the barometric observations differed for the two eruptions that reportedly released similar explosive energy levels. The Hunga eruption also provides an opportunity for extensive stress testing of analysis techniques and the carrying out of multi-technology investigation as shown in O1.4-085 and in P1.4-792, which in



O1.4-085: Seismic source time functions calculated from 109 stations at distances of 4400 km (40°) to 10000 km (90°). Green lines indicate the times of the events at 04:01, 04:15 and 04:18 UTC, respectively. ***Top*** *the three panels show the source time function inversion results based on the single force sources, moment tensor sources from seismic moment tensor inversion and explosion source.* ***Bottom*** *the panel shows the seismic source time function of Poli & Shapiro (2022) as depicted in Vergoz et al. (2022) for comparison.*

S Donner, A Steinberg, J Lehr, C Pilger, P Hupe, P Gaebler, J O Ross, E P S Eibl, S Heimann, D Rebscher, T Plenefisch, L Ceranna, The January 2022 Hunga Volcano explosive eruption from the multitechnological perspective of CTBT monitoring, Geophysical Journal International, Volume 235, Issue 1, October 2023, Pages 48–73, https://doi.org/10.1093/gji/ggad204

turn highlighted the limitations of the methods for this large scale explosive volcanic source. As shown in P1.4-487, owing to the source type and the activity over an extended period, the sequence additionally offers an opportunity to accurately characterize the seismicity related to the volcanic activity, which leads to two different source mechanisms, resupply of magma and collapse, over three months. Infrasound observations from a stratospheric balloon presented in P1.4-821 lead to detection of signals circumnavigating the earth over

nine days as a result of an improved signal to noise ratio compared to ground observations, while simulation of the dispersion of volcanic ash shown in P1.4-733 demonstrated the need for a specific configuration in the case of a large scale underwater eruption.

The monitoring of near earth objects impacting the atmosphere was the second most covered topic of the session with one oral presentation and two e-posters. In September 2020, a rare occasion of earth grazer occurrence over Europe observed by traditional observation techniques was uncommonly captured by infrasound sensors as it crossed the upper regions of the atmosphere with a shallow angle, as reported in O1.4-540 (in a pre-recorded video). Other studies presented the capabilities for monitoring atmospheric impacts from near earth objects with infrasound technology as in P1.4-482 or how simulations can help understand the impact risk as well as source discrimination as in P1.4-272.

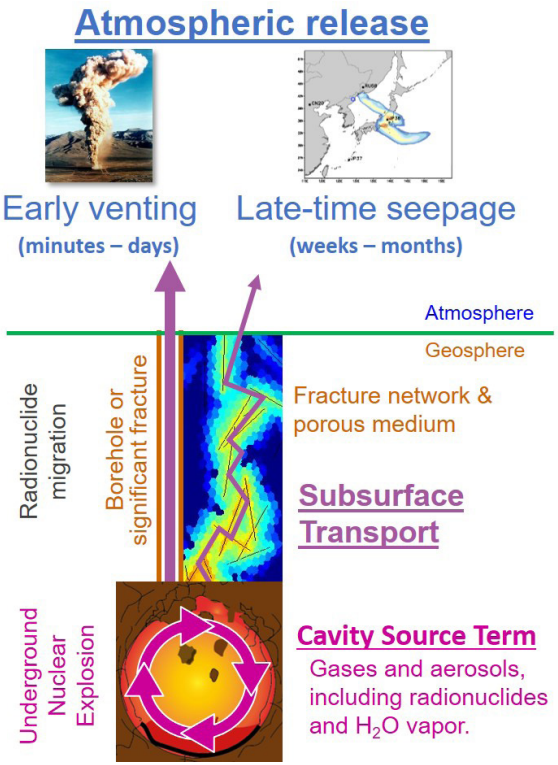
With the development of renewable energies, wind turbines are being constructed globally. Authors in Europe are interested in the work presented in P1.4-112 and P1.4-587 to quantify their negative impact on IMS facilities or to estimate their contribution to the ambient seismoacoustic noise field. This is an important field of research for the PTS as findings will contribute to IMS seismic and infrasound station installations or recapitalization. Researchers are interested in the link between infrasound technology and climate change in Antarctica and argue for the complementarity of the technology with other observation methods in P1.4-053. The question of conversion at the interfaces is considered by the authors. First, the case of advancing the understanding of hydroacoustic signals coastal conversion is made as T phase stations record signals of interest that are underused in the IDC products presented in P1.4-584. Then the complexity of the earth–atmosphere interface for the case of the 2020 Beirut (Lebanon) explosion is studied in P1.4-795 with the aim to offer a physics based propagation model providing reasonable joint seismoacoustic yield estimations.

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, nationally, regionally or globally. Such events can be located in time and space, and their characteristics can be estimated based on the data products collected. This theme covers the characterization of the source, the signals being emitted 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, acoustic, 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 policymaking. One of the challenges facing an inspection team at a historic test site is the need to distinguish and identify observables generated by historic underground nuclear explosions (those conducted before the nuclear testing moratorium) and those resulting from a more recent event.

T2.1 Characterization of Treaty-Relevant Events

For the waveform topics, the session presented progress in data analysis, source mechanism and transmission characterization. In O2.1-326 the Green's functions between the nuclear test

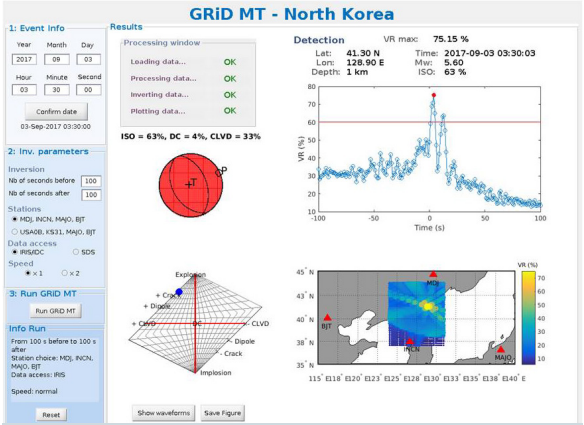


O2.1-118: The atmospheric source term is different from the cavity source term and it determines the activity concentrations recorded at monitoring stations. However, determining the atmospheric source term is not straightforward.

Photo of the Baneberry nuclear test (18 December 1970) courtesy of the National Nuclear Security Administration/Nevada Site Office.

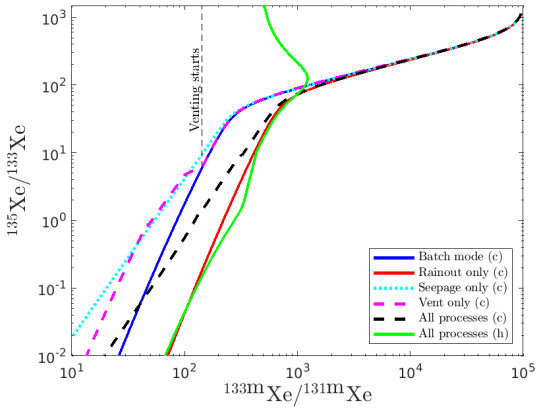
source locations in the Democratic People's Republic of Korea and a seismic station located 373 km to the north were estimated based on data recordings. Source parameters and time functions were also derived for each of the underground nuclear explosions in the Democratic People's Republic of Korea. The study showed that the two tests in 2016 created weak fractured zones close to the site of the 2017 Democratic People's Republic of Korea 6 test. Seismic data from collapses associated with mining activity or nuclear testing were studied in O2.1-164 to characterize these kinds of events, which have many identifying features similar to explosions. Progress made toward the development of a collapse source model, as complementary to the more commonly recognized earthquake and explosion source models, was presented along with possible identification methods. Rapid full source characterization using full moment tensor inversions based on long period seismic waveforms recorded at regional distance was used in a rapid detector of seismic events providing the full information about the sources (origin time, location, magnitude and mechanism) was presented in O2.1-290. The method is useful for rapid detection of nuclear tests, monitoring of small earthquakes and in the detection of large magnitude earthquakes for tsunami warning centres. Systematic events discrimination at the Kenyan NDC was presented in O2.1-638, where a step by step procedure of events discrimination was applied to seismic events.

Various e-posters addressed seismic data analysis from the nuclear tests in the



O2.1-290: Interactive tool for grid based real time determination of moment tensor (GRiD MT) for analysts.

Democratic People's Republic of Korea. P2.1-222 explored denoising techniques with machine learning to improve moment tensor analysis. P2.1-806 used seismic data analysis, spectral and time domain methods to discriminate, detect and locate seismic events and micro-earthquakes induced by nuclear tests. P2.1-743 introduced improved joint inversion with a layered velocity model, enhancing source depth recovery and yield estimation. P2.1-600 estimated root mean square Lg wave amplitude for underground nuclear tests in the Democratic People's Republic of Korea, correlated with mb from teleseismic stations, suggesting its utility for yield estimation. These e-posters contributed valuable insights into seismic monitoring and verification efforts for nuclear tests in the Democratic People's Republic of Korea.



P2.1-678: Four radioxenon plots for discriminating UNEs and civilian applications: 1). The basic case shows blue curve for the well-mixed and closed system. The red curve on the right side of blue is for rainout only. The dotted cyan curve on the left of blue is for seepage only. The dashed magenta curve also on the left of the blue is for venting only at 1 day. 2). The dashed black curve crossing over the blue curve indicates the rainout effect in early time and seepage and venting effect in late time. 3). The little (c) and (h) in the legend indicate the signal in cavity and host rock respectively. The correlation is location dependent. If we check signal in host rock, the correlation in green may be similar to the red curve in cavity.

Several lightening talks highlighted cutting edge approaches and technologies in nuclear test monitoring and characterization. To advance the understanding and capabilities in detecting and verifying nuclear explosions P2.1-509 presented a novel approach to estimate the yield of explosive sources. This research offers a promising method for accurately assessing the magnitude of underground nuclear explosions, contributing to improved monitoring and verification capabilities crucial for nuclear proliferation detection and disarmament efforts. P2.1-494 explored utilizing low frequency electromagnetic signals to investigate historic US nuclear test observations. P2.1-357 delved into the investigation of anomalous seismic events in India. Utilizing both Interferometric Synthetic Aperture Radar techniques and seismic methods, the study excluded nuclear origins for these events. It was demonstrated how, by integrating advanced geophysical techniques, the ability to accurately identify and distinguish between various seismic sources and their origins is enhanced.

The IDC processing pipeline was addressed in P2.1-575, where the performance of NET-VISA for false and missed events was evaluated. P2.1-287 evaluated mis-associated surface waves within the automated processing flow of the Reviewed Event Bulletin (REB).

Noble gas emission scenarios of underground nuclear explosions were investigated in O2.1-118 and P2.1-678 based on realistic models of cavity-physics of a nuclear detonation, including the cavity partitioning process, prompt venting owing to drill-back or pre-existing conduits or fractures, and late-time seepage due to barometric pumping. It was shown that radioxenon composition in a release from the cavity and host rock can be simulated with different parameters, which can be used for event discrimination and further, for estimation of the detonation time. Radioxenon background estimation and discrimination of CTBT-relevant nuclear events were addressed in a number of posters: a radioxenon event classification method based on the CatBoost machine learning algorithm (P2.1-553); a comparison study between real IMS observations, simulated concentrations of nuclear explosions and synthetic ones (P2.1-681); better estimation of radioxenon background based on measurements using transportable noble gas systems in the vicinity of an IMS station (P2.1-787); sample association to a given release scenario based on the evolution of activity ratios (P2.1-521) and potential benefits of high resolution ATM by using different meteorological inputs for case studies of the Democratic People's Republic of Korea (P2.1-507).

The coincidence of radioiodine and radioxenon observations at co-located systems may offer an opportunity for event screening based on the isotopic activity ratios of radioxenon to radioiodine, including the source terms of underground nuclear explosions and nuclear facilities (nuclear power plants and medical isotope production facilities), as presented in P2.1-323 and P2.1-324.

T2.2 Challenges of On-Site Inspection

Topic 2.2 covered a range of challenges related to the preparation and conduct of OSIs in various environmental conditions (P2.2-

576 and P2.2-596). The session also covered various challenges related to the application of inspection techniques (O2.2-178, P2.2-354, P2.2-467, P2.2-625 and P2.2-855) during an OSI.

A comprehensive overview of challenging environments and their classification was provided in P2.2-576. The potential occurrence of a fire in an inspection area and its impact on the conduct of OSIs was presented in P2.2-596.

Presentation O2.2-178 highlighted the importance, and at the same time challenges, of the use of robotic systems and/or remotely controlled measurement platforms for the characterization of the Treaty-relevant events. The presentation highlighted that robotic platforms offer safer, more affordable and efficient ways to collect multiple data modalities, including visual and thermal infrared information, also in challenging environments. It also highlighted that robotic platforms may provide increased data collection efficiency over broad areas, relative to other surveying methods, to facilitate anomaly and artifact observations.

The use of open source information including open source satellite imagery was highlighted in O2.2-682. It pointed out that in environments where there is relatively little available open source information, the analysis of satellite imagery data can be of particular value in monitoring for indications of nuclear weapon test preparation activities, such as signs at suspected nuclear weapon test locations of increased vehicle traffic, construction of support buildings and tunnel excavations.

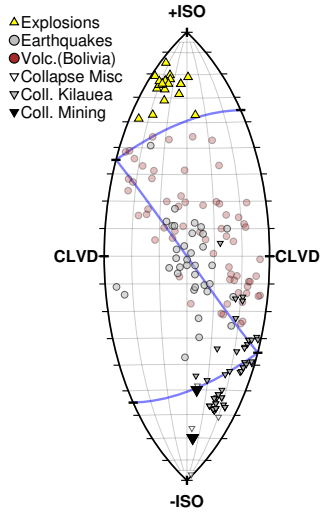
Recent innovations in the chain of custody of environmental samples during OSIs was provided in detail in P2.2-855. It highlighted the fact that tracking a reliable chain of custody during an OSI can be laborious, but it is mandatory as it must ensure that the evidence collected is authentic and traceable.

Results of a case study in the application of resonance seismometry to identify surface ground zero of a past explosion were presented in P2.2-467. Similarly, results of a numerical simulation of signatures of a cavity created by an underground nuclear explosion in 2-D exploration seismic data was presented in P2.2-354.

T2.3 Seismoacoustic Sources in Theory and Practice

Session T2.3 had five oral presentations and 26 e-posters covering a range of analysis of seismoacoustic sources.

Distinguishing between an explosion, an earthquake or a cavity collapse is one of the important CTBT monitoring tasks. Experimental explosions conducted around natural seismicity and former test sites provide a valuable data set as a basis for finding signal characteristics of diverse types of sources recorded at the same station. Several source physics experiments have been completed in the past, the one which is currently planned will involve placing explosive devices at up to depths of 2 km in the Rock Valley, Nevada, USA. Experiments will be a direct comparison of an earthquake and explosion at the same location – the ultimate test of identification capabilities (O2.3-171 and O2.3-270). Discrimination was a topic of interest in several presentations



Screening with moment tensors

O2.3-448: Explosion events can be screened from other seismic events through their moment tensors and source types. The figures shows that different events separate into different areas of the source type lune, with explosions at the top, earthquakes at the centre and collapses at the bottom.

demonstrating the vivid interest of the scientific community in this important topic (P2.3-484 and P2.3-525).

Moment tensors may be used as a method of routine and robust differentiation among explosions, earthquakes and cavity collapses. The method was assessed from three sources related to mining activity in Sweden, Tennessee, USA and on the Kola Peninsula, Russian Federation. Analysis with moment tensors, based on IMS and open station data, correctly identified them as a cavity collapse. This method may complement current IDC screening algorithms. Moment tensor analysis of data from announced tests in the Democratic People's Republic of Korea correctly classified these sources as explosions (O2.3-448) as for other former test site location (P2.3-166, P2.3-410 and P2.3-490). A similar method is further used with the objective to constrain source parameters using multi-observation techniques (P2.3-317).

Knowledge of regional seismicity, repetitive underwater sources and infrasound activity may help to validate and identify unusual events. Several seismoacoustic bulletins were included in the session, one of them was the Korean Infrasound Bulletin; a collection of infrasound data that started 24 years ago. Six regional infrasound arrays in the Republic of Korea and two IMS infrasound stations contributed to the location of more than 35 000 events. Given the sparce nature of the IMS network, this regional bulletin provides valuable information about man-made activity in the area (O2.3-340). Seismoacoustic analysis of recent underwater explosions captured the interest of research groups that presented their interpretation using diverse detection and location techniques (P2.3-306, P2.3-571 and P2.3-804).

Several known sources, anthropogenic (chemical or mining explosions) and natural, (landslide and earthquake) were investigated at the local, regional and global range, demonstrating the challenges faced by the scientific community in discriminating between sources and in characterizing sources based on the current knowledge of the various propagation mediums, either the solid earth, the oceans or the atmosphere (O2.3-744, P2.3-432, P2.3-234 and P2.3-825).

T2.4 Atmospheric and Subsurface Radionuclide Background and Dispersion

This session included five oral presentations and 47 e-posters, making it one of the largest sessions at the conference. Highlights from the session are given below.

Molten salt reactors are currently under development and testing in various countries. The first one is planned to go into operation in 2025 (P2.4-592). Molten fuel provides an opportunity for continuous processing of gaseous fission products. Simulations performed for four molten salt reactor designs indicate that for the case of continuous reprocessing of the fuel salt, the radioxenon and radioiodine signatures are indistinguishable from a nuclear explosion (O2.4-393). Since it can present additional challenge for interpretation of IMS measurements, it is recommended to add, as part of the design criteria for molten salt reactors, a retention system that would postpone the release by, for example, 30 days.

The performance of new noble gas systems continues to be revealed after the success of the SAUNA III system was presented at SnT2021. A summary of radioxenon detections with the SPALAX-New Generation system concludes that the number of detections has drastically increased (P2.4-459). The activity concentrations measured by Xenon International are consistent with data from the current operational IMS system SPALAX at radionuclide monitoring station RN33 on Mount Schauinsland, Germany (O2.4-497). Due to approximately one order of magnitude higher sensitivities of Xenon International and shortening sampling time to six hours, it is possible to detect lower activity concentrations of Xe-135 and metastables, i.e. Xe-131m and Xe-133m. In the case of measurements of metastables collected after spikes, the memory

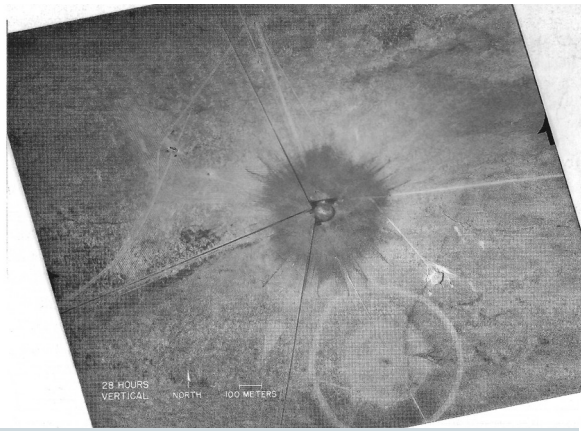
effect was observed. This demonstrates that the twofold increase in sampling frequency with the Xenon International system enhances the localization capability which was confirmed with stack release data (P2.4-818) collected by the Source Term Analysis of Xenon (STAX) project (P2.4-243, P2.4-341 and P2.4-367). The impact of a gas cooled nuclear power plant on the atmospheric background of radioxenon was explored with a comprehensive experiment conducted by the Xenon Environmental Nuclide Analysis at Hartlepool collaboration using a STAX detector (P2.4-370 and P2.4-049). Further advancements refer to ATM studies of nuclear testing events and the resulting radioactive signature, which supports hypothesis testing and the accompanying classification of sources (P2.4-302 and P2.4-673). Scientific solutions are investigated for the radioxenon background estimation and related implementation of a screening flag in IDC products (P2.4-335).

Underground nuclear explosions induce a strong flow of air through the surrounding fractured porous media, which carries radionuclides or chemical species, like water vapour H_2O, radon and CO_2 (O2.4-059). Simulations demonstrate that radon cannot be detected at the monitoring site while H_2O and CO_2 outbursts could possibly be detected at the test site by satellite imaging depending on sensitivity. If the underground explosion of 150 kt would be at a depth of 550 metres in a granitic rock, Xe-133 could be easily detected one day later 1000 km away at the monitoring site. A similar end to end numerical simulation of explosion cavity creation, cavity circulation processes, subsurface gas transport and prompt atmospheric releases is reported in P2.4-271. The detectability of prompt and delayed venting with different degrees of fractionation is studied based on simulated fission products from an underground nuclear explosion (P2.4-361).

T2.5 Historical Data from Nuclear Test Monitoring

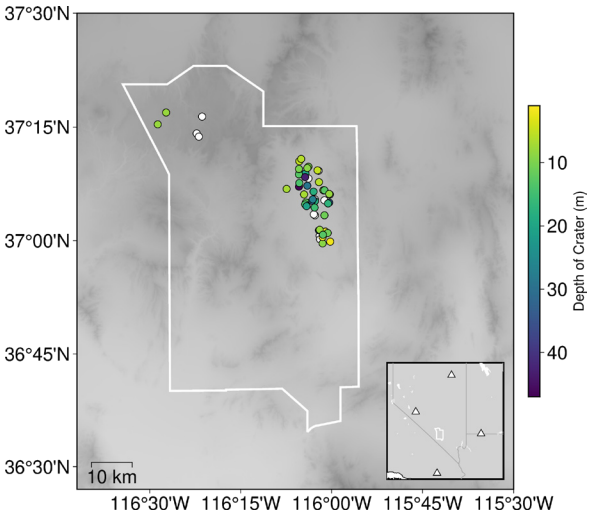
Historical data from nuclear tests are a precious and most relevant source for nuclear explosion monitoring. Most presentations dealt with seismic data. A group of presentations used recordings of nuclear and chemical explosions in the region of the Semipalatinsk Test Site, Kazakhstan (P2.5-395, P2.5-426 and P2.5-543), Soviet Peaceful Nuclear Explosions (P2.5-496), US underground nuclear tests (P2.5-500) and the Lop Nor, China, test site (P2.5-190 and P2.5-329). For example, O2.5-417 studied the spatio-temporal variations of the short period S wave attenuation field. These data are useful for discrimination of the underground nuclear explosions and studying geodynamic processes in the regions of large test sites.

Two specific historic nuclear tests were the topic of dedicated presentations. O2.5-518 presented a general discussion of analogue seismic data and corrected the origin time for the first nuclear explosion known as Trinity. P2.5-837 dealt with possible historical seismic recordings of the 6 July 1962 Sedan, Nevada, USA, nuclear explosion.



O2.5-518: Locations of the Trinity test and the 108 tons TNT chemical explosion that was conducted 70 days earlier.

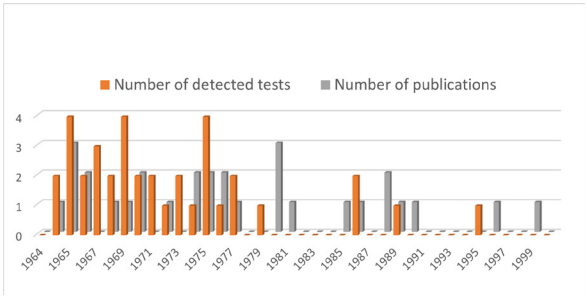
Several presentations dealt with special repositories of historical data. P2.5-186 covered the relocation of the Central Asia comprehensive seismic bulletin, P2.5-238 presented the Waveforms from Nuclear Explosions Repository and P2.5-439 described how the Air Force Technical Application Center, USA, collects, preserves and integrates historical geophysical data. P2.5-450 introduced the CTBTO link to the International Seismological Centre (ISC) database which



O2.5-138: Locations of recovered legacy collapse events coloured by depth of crater (if known) from shallowest (yellow) to deepest (purple). Unknown crater depths are indicated by white circles. Boundaries of the NNSS are indicated by the white outline. Inset: Location of NNSS (white outline) relative to the seismic stations of Livermore Nevada Network (white triangles).

provides access to current and historical seismic data. O2.5-138 presented previously unreleased nuclear tests and collapse data from the Livermore National Network between 1979-1992 and discussed the challenges in preserving and correcting the waveforms.

While most ongoing efforts still focus on seismic data, it was noted that access to historical hydroacoustic and infrasound data are still rare and radionuclide data are sparse. P2.5-653 discussed achievements, changes and challenges of the 25 years of seismic, hydroacoustic and infrasound data analysis at the CTBTO. The presentation on frequency of radionuclides reported in remote atmospheric observations of historic nuclear test explosions (P2.5-320) builds on a similar oral presentation at SnT2021 but makes a big step forward by comparing current monitoring



P2.5-320: The timeline shows the dates of 30 publications and of 37 nuclear tests which were associated with remote observations of atmospheric radioactivity described in these publications. It is becoming apparent that some of these publications appeared soon after the nuclear tests took place and others were delayed by several years.

practices against historical experience. The other presentation on radionuclide data (P2.5-121) dealt with monitoring traces of radio-caesium in Indonesian waters and land masses as an indicator of historic nuclear weapon testing activities.

In conclusion, this session confirmed the increasing interest in historical data from different regions and geological characteristics. Signals from nuclear tests in the atmosphere, underwater and underground are recognized as the most relevant references for developing, validating and testing methods and procedures for nuclear explosion monitoring.

Theme 3: Monitoring and On-Site Inspection Technologies and Techniques

This theme focuses on the systems used for the monitoring of nuclear explosions and the processing of the recorded data. This includes advances in traditional areas such as seismic and radionuclide instrumentation, sensor networks and processing methodologies, as well as the exploration of novel methods and the adaptation and integration of methods used in other fields. For every sensor technology special data processing and analysis methods are applied. The three waveform technologies (seismic, hydroacoustic and infrasound) are analysed together to build events. The integration of radionuclide and waveform results can be achieved with ATM. The integration of IMS data with other data types and different sources creates additional challenges and benefits. 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. Diverse sources of remotely sensed data, whether from satellites, aircraft or remotely controlled measurement platforms, may be of

use in nuclear explosion monitoring.

T3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications

Substantial progress has been made by the scientific and metrology communities over the past few years in characterizing the response of infrasound sensors in laboratories, targeting traceability to the international system of unit (P3.1-724, P3.1-646 and P3.1-671). The oral presentation O3.1-676 featured the results of an interlaboratory comparison organized by the PTS and involving five participating laboratories: the Laboratoire national de métrologie et d'essais, France; the Pennsylvania State University, USA; the Commissariat à l'énergie atomique et aux énergies alternatives, France; Sandia National Laboratories, USA and the University of Mississippi, USA. The comparison demonstrated the equivalence in calibration results across laboratories for most of the IMS frequency band of interest. These contributions are essential to ensure consistency in IMS measurements and equivalence in data produced across the IMS network.

In light of the recent developments in quality assurance for IMS infrasound measurements, laboratories show more and more interest to apply metrology to seismic sensors (P3.1-172 and P3.1-618), and to identify the current challenges and opportunities of the existing electrical calibration method, for instance its susceptibility to temperature (P3.1-860). Such developments are very relevant to the IMS seismic network and could lead to more precise equipment specifications for type approval.
While laboratory calibration methods are in development, work is also directed by the community at developing and assessing methods for on-site calibration. This was illustrated in the oral presentation O3.1-698, which focused on the determination of the frequency response of seismic and infrasound IMS station sensors using an on-site calibration approach. This work is well aligned with the current developments of the CalxPy software undertaken by the PTS for the calibration of IMS stations (P3.1-578).

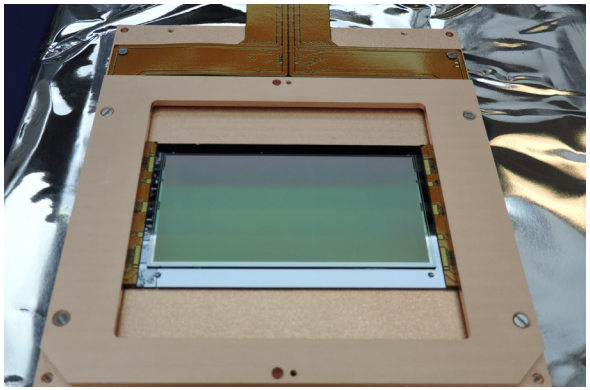
To identify the next generation of equipment to be deployed at IMS stations for recapitalizations and station upgrades, the PTS needs to keep abreast of the latest developments in sensors. Several e-posters addressed the design and assessment of new geophysical sensing techniques and sensors. Efforts in seismometer design focus on very large band sensors with very low self-noise and high resolution (P3.1-595) through promising innovations such as the integration of optical transducers (P3.1-313, P3.1-333 and P3.1-788). Other e-posters focused on assessing and repurposing subsea cables for geophysical observations by integrating environmental sensors (P3.1-280 and P3.1-797).

The monitoring of data quality and noise levels are core requirements of the draft IMS Operational Manual. A number of e-posters addressed these topics for the seismic and infrasound technologies, ranging from the characterization of site noise in the context of IMS station installation and upgrade (P3.1-192) to the effect of atmospheric conditions on ambient seismic noise (P3.1-558), the study of spectral characteristics of seismic and infrasound data recorded at IMS stations (P3.1-203) and the monitoring of environmental conditions to support the interpretation of geophysical data (P3.1-161).

T3.2 Radionuclide Technologies and Applications

Three oral presentations and 22 e-posters contributed to the scientific exchange on radionuclide technologies and applications. Contributions focused on the following areas: properties of noble gas adsorbents, improvements to the particulate collection process, detector technology, experience gained in the operation of new xenon measurement systems, improvements to laboratory detection systems and gas processing systems and new developments in field noble gas measurement systems. The oral presentations (O3.2-381, O3.2-345 and

O3.2-218) focused on detector technology for beta and beta–gamma counting applications. The highlights of the session are given below. Several developers, national and IMS laboratories presented their investigations to further improve and optimize beta–gamma coincidence detectors for measurement of noble gases, xenon and argon in particular (P3.2-392, P3.2-512 and P3.2-599). Research and development continued to optimize the contribution of IMS laboratories for the reanalysis of radioxenon samples for verification purposes (O3.2-381, O3.2-345, P3.2-371, P3.2-382 and P3.2-463). The requirements for detection systems differ between IMS stations and laboratories, as the latter receive the samples after a significant delay in relation to the radioactive lifetime of the metastable xenon isotopes. Compared to the measurement at IMS stations, the sample received at IMS laboratories will have different activity and activity ratios. Consequently, the best detector solution for laboratories may differ from those deployed in IMS xenon systems. Some detectors offer higher sensitivity at the cost of resolution and vice versa. Some groups are investigating the optimal combination of existing detector types, but also new detector designs are being studied. One example was an experimental pixelated silicon detector for detection of beta radiation, which shows improved noise performance and improved resolution compared to standard non-pixelated silicon detectors (O3.2-345). Another approach investigated was to increase energy resolution which improves the selectivity of the measurement and may promise increased accuracy. Other researchers are trying to establish the best combination of detectors to achieve the highest possible sensitivity. Different solutions may be implemented depending on the application, which are tailored for IMS stations, IMS laboratories or an OSI.



O3.2-345: Experimental highly pixelated silicon detector for detection of beta radiation with improved energy and spatial resolution.

Photo credit: Todd Hossbach (PNNL).

For particulate radionuclide stations and laboratories, a significant increase in sensitivity to a number of Treaty-relevant radionuclides can be demonstrated by the application of coincidence measurement techniques (O3.2-218 and P3.2-662). These techniques have been shown to provide high sensitivity and selectivity for those radionuclides having coincident gamma or X ray emissions.

Research is continuing into new materials for noble gas (xenon and argon) adsorption from air and to better understand the adsorption processes of existing materials (P3.2-233, P3.2-803 and P3.2-877). First generation xenon systems were all relying on activated charcoal as an adsorbent. This is a well established process but relies on the complete and reliable removal of moisture content and it requires thermal cycling. Some of the newer systems have included silver exchanged xeolites. For the operation of IMS systems and field systems it is important to fully understand the adsorption process and new materials may promise a higher collection efficiency or sample volumes. Improved understanding of the adsorption process may increase the robustness of noble gas sampling.

Research and development continue into the electrostatic collection of airborne particulates (P3.2-268, P3.2-662, P3.2-746 and P3.2-829). Compared to collection by filtration media this sampling technology potentially can offer a higher sample volume than current IMS and OSI systems at reduced power consumption. The reduced power demand promises longer sampling times for OSI and reduced operational costs and

robustness for IMS station operations. For IMS use, the new sample geometry will allow more sensitive measurements as compared to filter geometries currently used. A full scale Radionuclide Aerosol Sampler Analyzer (RASA) type sampling unit will be tested in the coming years, with a potential incorporation into a RASA2 sampling and measurement unit.

P3.2-746: Design drawing for an IMS type sampling system (manual or automated) utilizing electrostatic collections. A ruggedized prototype is planned to be tested by the developers in the next two years.

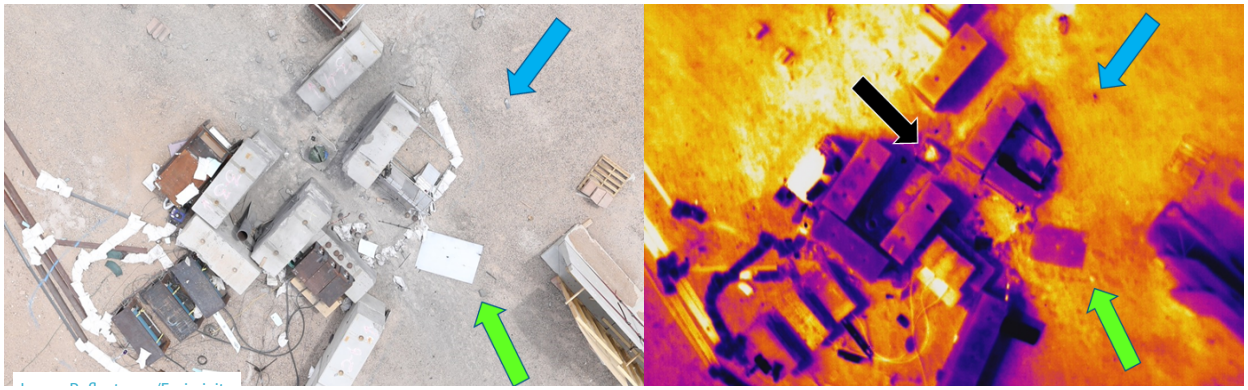
T3.3 On-Site Inspection Techniques

Topic 3.3 encompassed a spectrum of papers that addressed techniques or data of potential relevance during the launch phase of an OSI, the platforms and sensors used during an inspection as well as alternative methods to process data.

Five papers addressed the use of data from space based sensors; while three focused on optical imagery (P3.3-144, P3.3-224 and P3.3-839), papers P3.3-294 and P3.3-778 considered the use of synthetic aperture radar. The latter considered the use of synthetic aperture radar for OSIs in a challenging marine environment. P3.3-425 considered another challenging environment – an OSI in a mountainous environment. In this case, the application of a range of deep geophysical techniques in a densely vegetated area with steep topography and at high altitude was presented.

Remotely controlled measurement platforms featured prominently in a number of papers reporting on the platforms themselves and the OSI-relevant sensors that could be mounted onto those platforms; these principally focused on technical aspects (e.g. magnetic survey, P3.3-308), but the oral presentation O3.3-863 also considered the ethical use of such platforms. Infrared data acquired from a near surface remotely controlled platform was considered in O3.3-689, which, for the first time at an SnT conference, presented the findings of the application of infrared photogrammetry to identify and locate OSI-relevant observables. While submitted papers focused on near surface remotely controlled platforms, it is worth highlighting the use of ground based platforms capable of carrying materials for support activities and also for inspection related activities, which was demonstrated as part of the exhibition at SnT2023.

For passive seismic monitoring, two papers were presented. O3.3-127 addressed the error associated with far-field approximation, while P3.3-466 covered the concept of nanoseismic monitoring and the software tools used to



O3.3-689: Thermal sensors, having much lower resolution than traditional RGB cameras, collect brightness temperature (reflectance/emissivity/intensity) values for every pixel.

address data collection in a mountainous environment. Stemming from passive seismic monitoring requirements, but now more broadly applied, P3.3-428 discussed the application of data transmission from sensors in the field via a repeater station to the base of operations.

On the issue of environmental sampling O3.3-387 compared the portioning of samples under the CTBT, the Chemical Weapons Convention and procedures followed by the International Atomic Energy Agency. With respect to energy resolution analysis, the application of gamma imaging featured in P3.3-086 and, following on from papers at previous SnT conferences, the use of such detectors in an OSI context as part of the panel discussion on technologies was discussed (Panel 2.4). The use of alternative sample holders in the laboratory was presented (P3.3-850) and a novel portable radioisotope identification device was also reported (P3.3-471). Noble gas techniques also featured prominently, with papers covering the fundamentals of the technique (P3.3-454 and P3.3-458), on sampling (P3.3-356 and P3.3-362), laboratory techniques (P3.3-563) and improvements to the OSI field laboratory itself (P3.3-634).

T3.4 Integrating Data from Different Monitoring Technologies

This session explored the challenges and benefits of integrating data of different types and sources. The six e-posters explored techniques and methodologies of combining different types of IMS data, combining IMS data with regional seismic and satellite data and the use of regional weather forecasting models. The authors explored how adding in additional data sources enhanced their ability to answer fundamental questions about the event source, as well as the need to have tools to be able to read and process these diverse data types.

An introduction to the data sources available was presented in P3.4-573. This e-poster provided an overview of the IDC, IDC history milestones and the status of the IDC progressive commissioning plan. The benefits of combining IDC data with additional data was explored in P3.4-572**.** Here the authors explored how the use of national data might assist in-depth NDC analyses or the PTS in conducting an expert technical analysis of an event of interest. The authors revisited the 2019 National Data Centre Preparedness Exercise scenario, where a fictitious nuclear explosion was based on a real ML 3.7 shallow tectonic seismic event within an earthquake swarm. By combining local seismic data with IMS primary and auxiliary data, the benefit of adding in additional data was explored, including the effect on event location, regional screening and waveform correlation based clustering. This e-poster also showed how to use the ISC link on the Secure Web Portal to search for events in the earthquake swarm.

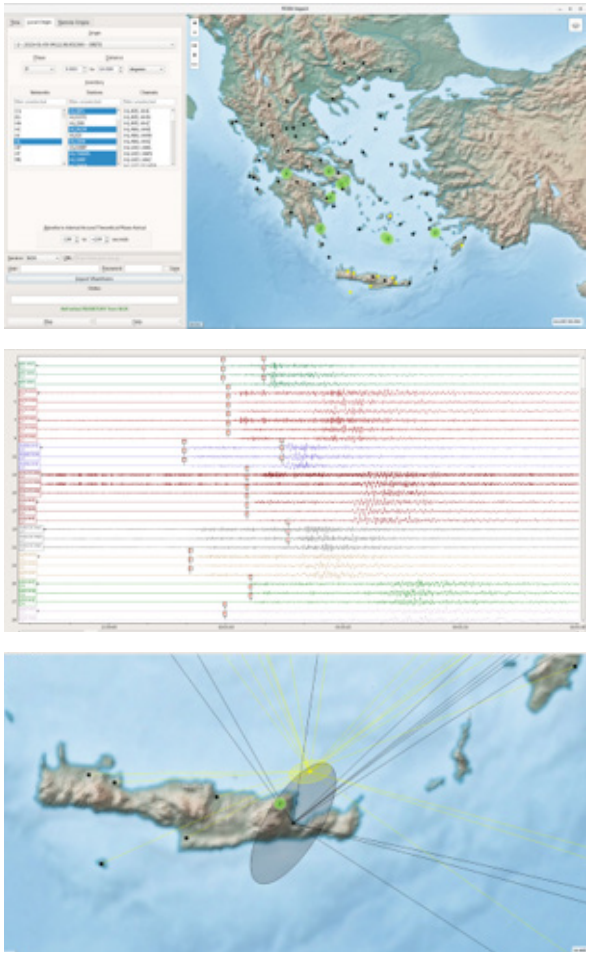
The e-poster P3.4-725 explored the use of non-IMS data, namely Interferometric Synthetic Aperture Radar satellite data to generate interferograms and deformation maps for several earthquakes in the Balkan Peninsula region, including the major earthquakes in Türkiye and Syria in 2023. It showed how the satellite data provides precise special resolution and enhances the understanding of the event. However, Interferometric Synthetic Aperture Radar does not work so well in regions of high vegetation, hence the need for data fusion approaches. The authors detail that they received the Sentiniel-1 data via the open access hub at https://scihub.copernicus.eu/ and that they used the software SNAP (freely distributed by the European Space Agency) for processing the data.

The e-poster P3.4-513 also explored the use of satellite imagery. The e-poster demonstrated the use of multi-technology fusion between the four IMS technologies and national technical means, such as satellite imagery, to overcome limitations in each individual data type. One example explored made use of infrasound and satellite imagery for the analysis of the Stromboli (Italy) eruptions on 3 July 2019. The synergy between infrasound and space observations for volcanic eruptions

enabled the gathering of relevant information about ash injection in the atmosphere even when satellite information was not available due to cloud coverage. Another example used infrasound and seismic data to find the time of a mining blast in Tunisia and distinguish sources in areas with low seismic network coverage. The author pointed out that software limitations impacted the analysis, as most software packages used were not optimized for data fusion.

Two e-posters focused specifically on software enhancements to enable easier integration of additional data types. The e-poster P3.4-407 showed the new data import features in the Geotool software version 3, which allow the user to easily import both IMS and non-IMS waveform data. Now users can import data from within the software, and users can easily access data, information and metadata from the International Federation of Digital Seismograph Networks compliant web service, similar to the Incorporated Research Institutions for Seismology and the GeoForschungsZentrum (allowing the integration of non-IMS data). An example showed how a user would load waveform data associated with a REB event and then supplement that with waveform data from 14 regional, non-IMS stations, and locate the event with a higher accuracy thanks to the increased number of observations.

Similarly, the e-poster P3.4-488 focused on the development of tools to allow researchers to use a wide range of weather research and forecasting (WRF) models. The key advancement was the development of Python packages to allow for plug and play workflows to make it easier to do high resolution ATM to support operations, debugging or experimental use. The chain of activities needed to produce custom meteorology files from WRF and make them available to the modelling software FLEXPART-WRF for a successful simulation is complex and prone to failure for a number of reasons, and the work described here is aimed at abstracting the inherent complexity into an easy to use system.



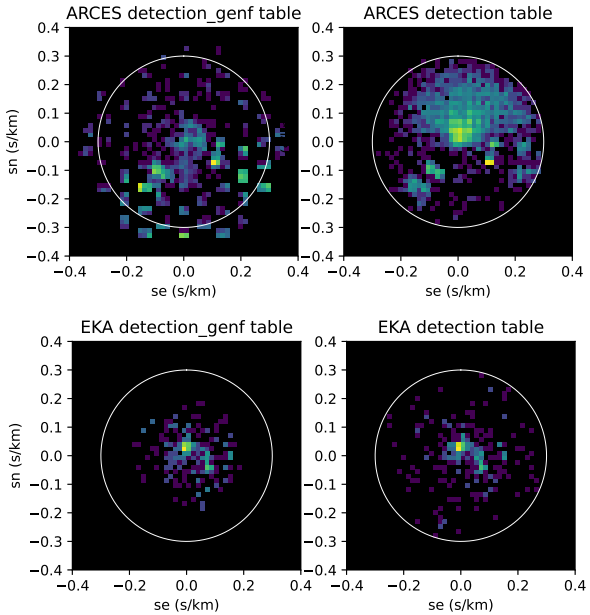
P3.4-407 Process to add non-IMS local/regional stations to the NDC-in-a-Box (in Geotool) for refining event parameters.

T3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data

This theme comprised six oral presentations and 41 e-posters. It included oral and e-poster presentations on a variety of topics including signal processing, data analysis algorithms, event location, analyst workload reduction, machine learning and deep learning, bulletin quality, event classification and others.

NET-VISA, the event detector/phase associator that will eventually replace the current IDC Global Associator (GA), was the focus of one oral and three e-poster presentations. In O3.5-424 the status of NET-VISA and how it compares with the GA based on a variety of performance measures were described. P3.5-461 and P3.5-892 discussed the effect of the event definition criteria on events created by NET-VISA and concluded that if these criteria are relaxed this will have a positive effect on

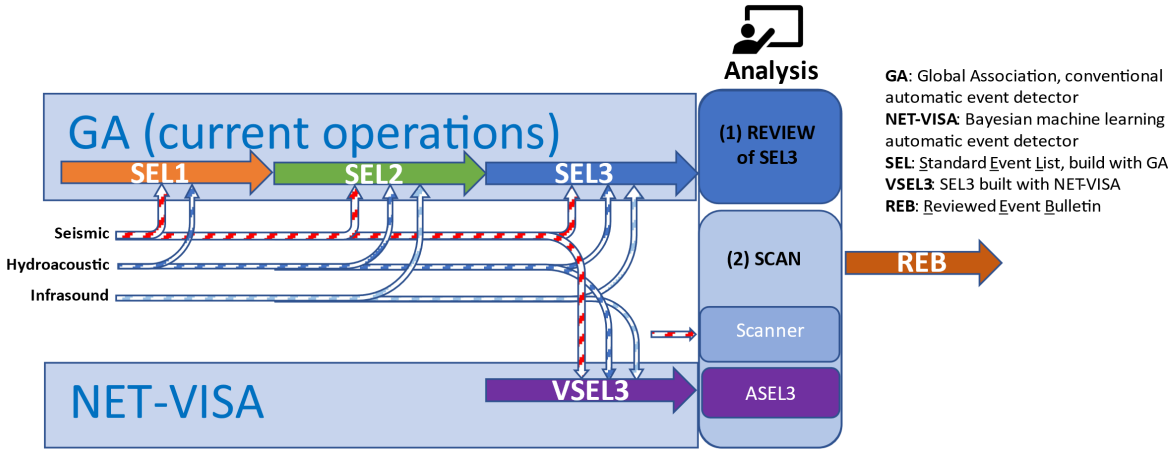
the number of Late Event Bulletin events that make it to the REB and the analysts' workload. Finally, in P3.5-891 it was suggested that the deliberate injection error in the distribution of the event location prior helps to better calibrate the error in the origin location.



*03.5-285: Vector slowness analysis of genF detections at EKA and ARCES arrays. **Left** genF detection vector slowness. **Right** IDC fk vector slowness.*

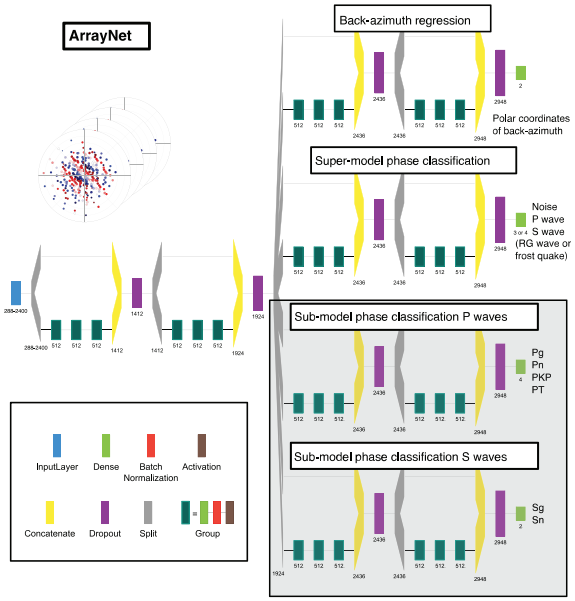
More studies evaluating various aspects of IDC processing were presented in the oral session. In 03.5-285 it was pointed out that the seismic arrays of the IMS have a variety of apertures, a number of elements, designs and signal and noise characteristics, and all these aspects should be taken into account and tailored to each seismic array. In particular, in 03.5-256, a comparison between the REB and the ISC bulletin for October 2020 showed that the percentage of matching events is high, however, the percentage of events with non-intersecting error ellipses obtained in this study is high compared to previous studies (this could be attributed to the increase in the number of IMS stations currently in use). A similar study (P3.5-656) over all 2020 events showed that location difference at less than 0.5 or 1 degrees between the REB and ISC as well as REB location accuracy are consistent with previous studies. Also it was noted that only about 30% of the REB events have an error ellipse area of less than 1000 square kilometres, which is the maximum uncertainty that triggers an OSI, and concluded that improvements in advanced location procedures do not seem to be translated to a better performance of the REB.

The hydroacoustic community focused on high performance computing. In particular, in P3.5-396 a graphics processing unit (GPU) implementation of the range dependent acoustic model, a standard 2-D Helmholtz equation solver, was presented that performs broadband sound propagation simulations two orders of magnitude faster than a single GPU core. Such drastic speed-up means that even real time simulation of range dependent propagation may be realized soon. At the same time, in P3.5-331 a 20 times faster



03.5-424: Current setup of the IDC automatic processing pipeline. Analysts review events that are automatically created by the GA (Global Association) software and then scan for additional events created by NET-VISA.

speed-up was achieved in 3-D broadband T wave propagation modelling, that is, modelling that includes propagation of waves behind islands or seamounts due to diffraction and reflection. Further speed-up is expected with further GPU customization.



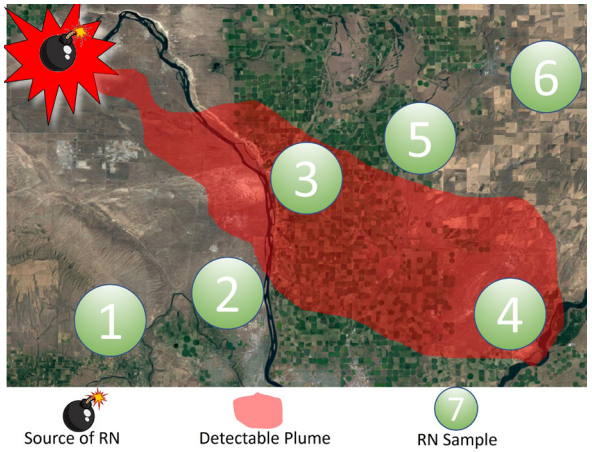
P3.5-282: Architecture of ArrayNet: a combined classification and regression neural network to circumvent the plane-wave assumption used for beamforming.

As far as event location is concerned, in P3.5-282 the authors used a combined classification and regression neural network to circumvent the plane wave assumption used in beamforming and more accurately label the phases and determine back azimuth directly from the arrival time differences between the array stations. This method seems to not only be more accurate than f-k beamforming but also faster (once the neural network has been trained). In O3.5-485 the authors presented a low complexity, robust parameter estimation method for periodic parameter estimation, the periodic Fisher-Scoring, to deal with the direction of arrival using seismic arrays; simulations showed promising results and more work is pending.

In P3.5-327 the authors tested and evaluated two supervised learning models, support vector machines and random decision forests, regarding infrasonic signal classification, namely among storm related sounds, quarry blasts and other anthropogenic activity. Other work on seismic event classification using machine learning and deep neural networks was presented in e-posters P3.5-123, P3.5-342 and P3.5-524.

T3.6 Analysis of Radionuclide Monitoring Data

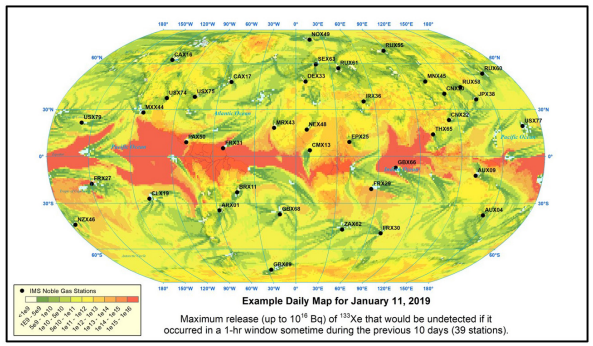
The topic contained contributions covering all aspects of analysis of IMS radionuclide data (aerosol and radioxenon), including instrument calibration techniques, spectrum analysis, estimation of uncertainties, isotopic ratios (O3.6-769), sample association (O3.6-364, P2.1-521 and P3.6-412), anomaly detection (O3.6-173), event dating and source location



O3.6-364: The development of an association algorithm for radionuclide measurements.

techniques (P2.4-334), possible improvements of the whole processing pipeline (P3.6-481) and IDC products, as well as new or further developed software tools. In particular, the session illustrated a trend towards an increased focus on the challenging problems of anomaly detection and sample association, as well as promising developments in the area of source location using Bayesian techniques (O3.6-239, O3.6-460 and P3.6-372). All of these problems are crucial in order to develop high quality IMS/IDC products that can be used by NDCs and in an expert technical analysis.

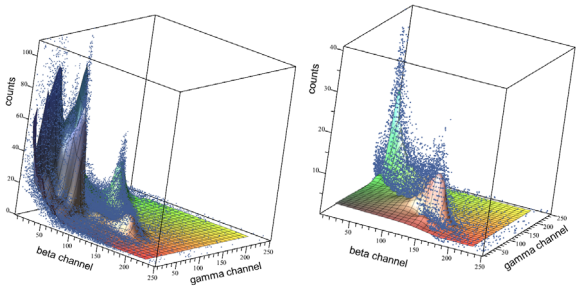
O3.6-173 discussed the possibilities of using machine learning methods for anomaly detection in multivariate radionuclide data. IDC currently uses the abnormal threshold



P3.6-481: Global sensitivity of IMS Noble Gas stations for a release of Xenon-133 at a given point on the earth.

for anomaly detection in one dimension, calculated using quantile data from previous measurements. To determine such quantiles in multivariate data can become difficult, a problem that can be overcome using standard machine learning techniques available in, for example, published Python packages. Examples were given for 2-D data using isolation forests, where a particular quantile can be shown to be related to the path length of the decision tree. In another example, anomalies in correlations between radioxenon data and atmospheric transport simulations were identified, providing quantitative 2-D anomaly scores.

Two talks described the performance of Bayesian location techniques. As discussed in 03.6-239, Bayesian location techniques have the possibility to shrink the geographical footprint compared to the standard field of



P3.6-095: "The Template Method", A New Method for Analyzing Daily Quality Control: Beta-Gamma Spectra for checking Energy Calibration.

regard/possible source region currently used in IDC tools. In addition, they can estimate parameter uncertainty and determine the release period and size. In a blind test, three organizations performed source reconstruction using synthetic data calculated for one long and one short range scenario, respectively. All participants used the Bayesian code FREAR, but with different meteorological models, software and reconstructions methods. The trials were successful, but the method requires careful selection of data points, and ensembles are likely to be required for realistic reconstruction performance.

In 03.6-460, a series of inverse modelling experiments was set up using Xe-133 observations associated with the former medical isotope production facility at Chalk River, Ontario, Canada. The purpose was to establish a baseline for source reconstruction data, methods and settings. A verification metric was used to compare different source reconstruction methods. For the test case, Bayesian inference and cost function optimization could localize the source within 800 or 270 km, using 5 or 15 days of observations, respectively. Using Bayesian inference, the true source sometimes falls outside the predicted source region, and deterioration can occur.

A new approach for automatic sample association using averaged historical air movement was presented in 03.6-364. Synthetic releases every 3 hours for a year were calculated for 100.000 globally distributed locations. The releases were used to construct a "detect versus non-detect" matrix for all 79 IMS radionuclide stations. The matrix can be used to calculate the 'affinity' for a certain location and any combination of detect versus non-detect by a station. This can be used automatically or manually as a launching point to associate samples at different stations to be used for source location. It also provides an initial look at possible source locations.

Contribution 03.6-769 discussed possible optimization of the radioxenon isotopic ratio screening flags through investigation of the most effective ratio thresholds and the best method for ratio uncertainty calculation using simulated releases from the Democratic

People's Republic of Korea test site detected at station RN38 in Japan. New screening flag thresholds were determined for four radioxenon ratios, which is one more than in current IDC operations. No combination of uncertainty calculation method and uncertainty interval was universally found to be superior.

Theme 4: Sustainment of Networks, Performance Evaluation and Optimization

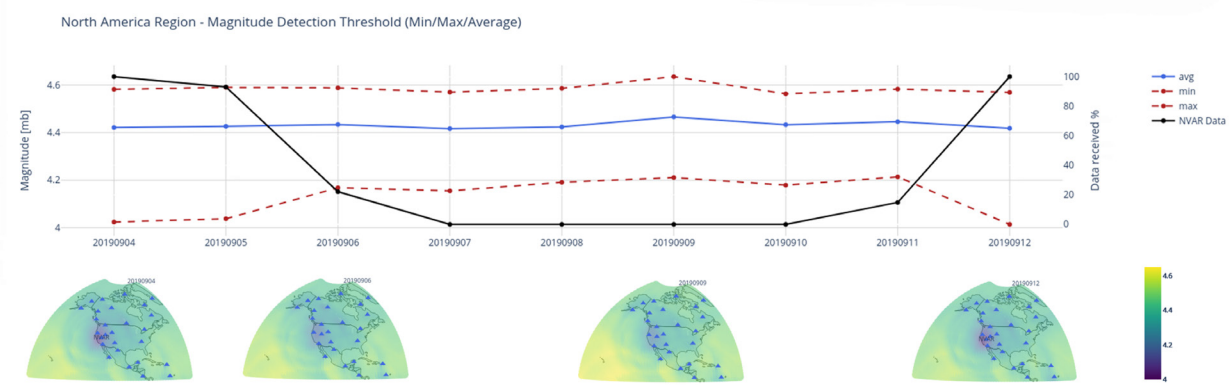
Operation and sustainment of a global network of monitoring systems poses substantial challenges. Near real time acquisition and forwarding of continuous and segmented data from the IMS and the subsequent processing and analysis of data at the IDC also present great challenges. Strict requirements for 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. In addition, the performance of the IMS and IDC critically depends on enabling technologies such as information technology (IT) and power systems. As the network nears completion and components reach the end of their lifetime, maintenance and sustainment become more and more important. The handling of OSI data is also subject to specific requirements outlined in the Treaty and the draft OSI Operational Manual. The objectives of the current work are to demonstrate OSI readiness on a system performance level and to assure the inspection team functionality (ITF). Beyond the IMS, IDC and OSI, the full Treaty verification system also includes NDCs. NDCs provide feedback to the IDC on its products and services, including the NDC analysis tools, and conduct preparedness exercises jointly with other NDCs. Optimization of the performance of the CTBT verification system involves other factors such as improvements in efficiency and cost effectiveness, reliability and security.

T4.1 Performance Evaluation of the International Monitoring System and On-Site Inspection and their Components

This session consisted of four oral presentations and 12 e-posters. Overall, the contributions focused on the verification responsibilities of the Technical Secretariat at entry into force to monitor, assess and report on the overall performance of the IMS and of the IDC. The presentations covered various aspects with the following three highlights: assessment of performance, detection capability and compliance with specifications, which are summarized below.

Assessment of network performance in (near) real time, considering failure identification and alert for maintenance:

The contributions pointed to the importance of early detection of potential failures and emphasized (near) real time monitoring as an effective support for control and evaluation (P4.1-722 and P4.1-079). Increasing data availability of an IMS station by minimizing downtime using notification systems to inform



P4.1-469: Changes in magnitude detection threshold computed with NetMOD tool (NETwork Monitoring for Optimal Detection) for period 4 – 12 September 2019, which include an outage for NVAR seismic primary station

on the need to start to solve an issue was also covered in this session. Presentations introduced tools for a global assessment of the IMS network performance (O4.1-582) and to assist the IDC in continuously monitoring and reporting on the operational status (P4.1-469). This included open source tools used in national networks that allow the detection of multiple problems in data transmission and provide basic data quality control (P4.1-120), the use of parametric data from seismic bulletins to identify changes in IMS station performance and evaluate station quality (P4.1-240), and on the usability of the state of health system to monitor in real time the status of the IMS (P4.1-314). Research tools using artificial intelligence (machine learning (P4.1-249) and an automatic data quality analysis system based on fuzzy logic (O4.1-479)) were also presented to assess station installation or station failure, to quickly diagnose equipment problems and to provide input and trigger the required engineering or maintenance activities (P4.1-598).

Network detectability and detection capability:
The importance of the capability of a seismic network to detect and identify small seismic events in a specific area was particularly highlighted (P4.1-043). The network detectability varies both in space and time and depends on several factors, i.e. meteorological conditions, anthropic noise, local soil conditions, etc. Not only is it important in the design of the network but also in determining whether it performs consistently as expected or needs to be improved. Of special relevance was the presentation of a web-based event detection capability assessment tool to map the detection capability of the IMS primary seismic network, for any time interval and geographical region system, using the event detection threshold (O4.1-582). This tool, available to authorized users having access to IMS data and IDC products, allows the performance of the network to be continuously monitored at the global, regional and local scales, estimate the detection capability and document it. Contributions on the need to continuously assess, maintain and improve the detection capability and location accuracy of regional networks were presented. This included examples of noticeable progress in increasing seismic event detection in local and regional networks over the last 10 years (O4.1-316).

Compliance with specifications and, in particular, calibration:
Compliance of IMS stations with the technical and operational requirements specified in the relevant operational manuals was a highlight of the session. Contributions included enhancements of data quality control tasks using interactive station monitoring tools in the IDC Operations Centre for fast and easy identification of data acquisition problems, as well as regular activities to ensure that station characteristics meet the requirements set forth in the draft IMS Operational Manuals (P4.1-670). Means of assurance of compliance with minimum requirements for stations that underwent major upgrades or equipment changes were also presented (P4.1-798). Of relevance in the session were the contributions on calibration. Controlling the quality of IMS data by comparing their scheduled calibration results against nominal values is a key point to strengthen confidence in its use (P4.1-714). A specific contribution on in-situ calibration of infrasound stations was presented (O4.1-051). This provides a continuous analysis that allows the monitoring of the performance of the stations in near real time, thus providing information on the status of detectors and feedback to the station operators. This information can be used to provide corrections to the raw signal data for retrieval of the corrected wave parameters.

T4.2 Systems Engineering for International Monitoring System and On-Site Inspection

The session aimed to gather recent technical advancements that have a potential to be integrated into the next generation of equipment, infrastructure and methods for both IMS and OSI, and that show potential for improving the agility and increase the performance of field activities. The main

messages conveyed can be grouped into three main thematic areas.

Solving problems related to harsh environments: Harsh environments are the norm rather than the exception and the most common problems encountered by stations deployed in such environments are related to power instabilities, noise interference and communication issues, factors that contribute to data quality or even data loss. Mitigation strategies include constant maintenance and support that can increase the sustainability of the stations. These mitigation strategies include backup power systems, shielding from electromagnetic interference, use of fibre optic cables for communications, increasing the number of field operations and providing standard operation procedures. (O4.2-369 and O4.2-731).

Increasing portability of the equipment: For OSI and for the IMS network the agility of the equipment becomes more important to ensure faster reaction. Portable and flexible solar charging packs have increased the power production. They are extremely portable and quick to deploy, with the power capacity providing an emergency charging supply to portable equipment during field operations. Lighter and more portable antennas for very small aperture terminals (VSAT), that can be deployed on vehicles, are easier to install, while enhancing bandwidth and ensuring less latency. Optical fibre geophone arrays are tested to provide solutions adaptable to field exercises to enhance the performance of the next generation of active seismic surveys. (P4.2-029 and P4.2-261).

Ensuring uninterrupted performance of the stations by using green energy supply: After more than 20 years of operation, the stations need refurbishment. AS72 in Norway is one example where preventive maintenance allowed continuity of data transmission. Moreover, with the integration of solar and wind energy for powering the equipment, it is an example of a green station. (P4.2-739).

T4.3 Enabling IT Technologies

The Enabling IT Technologies session was composed of 13 presentations, two of them being oral presentations (O4.3-152 and O4.3-456). The presentations can be categorized into the following sub-themes.

Data security and communication: These articles focused on enhancing data security, particularly within the IMS and nuclear facilities. They proposed innovative approaches to secure data exchange and safeguard sensitive information. Topics included new security schemes for wireless networks, secure multiparty communications, tailored data security solutions and hybrid cryptographic approaches. These contributions advance data security measures in alignment with international monitoring and nuclear control system requirements (P4.3-060).

Technological solutions and applications: These presentations covered a wide range of topics in technology, geophysics and nuclear science, emphasizing innovative applications and advancements utilizing modern technologies. Topics included space based Internet of Things constellations (P4.3-151), virtual reality for nuclear test simulations (O4.3 -152), seamless connections among seismological and stations of the global navigation satellite system, performance enhancements of atmospheric transport models using GPUs, m-Science systems for nuclear test monitoring, GPU based signal processing (P4.3-486), and smartphone based human activity recognition for earthquake signal processing. These contributions demonstrate the fusion of cutting-edge technology and scientific inquiry to address challenges in geophysics and nuclear science (P4.3-568).

Monitoring and data centre solutions:
Several presentations focused on optimizing monitoring systems, particularly in geophysics and data centres. They explored topics such as Global Communications Infrastructure support for virtual NDCs (P4.3-165), data modelling (P4.3-375), access architecture refinement in Geophysical Monitoring Systems, a web-based software tool for improving event bulletins (O4.3-456), NDC-in-the-Cloud solutions (P4.3-894) and Workflow as a Service for web-based monitoring services (P4.3-674). These contributions highlight technological advancements that streamline monitoring, data accessibility and quality assurance in geophysics and data centre operations.

Disaster recovery and communication networks:
P4.3-734 discussed the implementation of a VSAT network disaster recovery plan by the Indonesian NDC, aimed at improving data transmission and information sharing in meteorology, climatology and geophysics. The plan focuses on optimizing data management and communication during disasters, ensuring uninterrupted access to critical information.

Early warning and precursors:
The e-poster (P4.3-568) introduced an innovative approach that uses WiFi Channel State Information sensing to develop an intelligent alerting system for detecting early signs of earthquakes. This approach leverages changes in WiFi Channel State Information patterns caused by seismic activities to identify potential earthquake precursors. The goal of the study is to create an intelligent system that harnesses existing technology to enhance earthquake early warning capabilities, potentially contributing to improved disaster preparedness and response.

In summary, the session presented numerous practical IT solutions to support the PTS mission. For the future, it may be beneficial to involve technology leaders and innovative companies to explore solutions that align with the evolving needs of the IMS.

T4.4 International Monitoring System Sustainment

The session on IMS sustainment consisted of three oral presentations and eight e-posters. The presentations covered the four technologies of the IMS. The following major topics were identified:

Experience in PTS maintenance of radionuclide stations in the field (P4.4-630) as well as applying the state of health programmes in operation at the PTS were presented (P4.4-759). These programmes are undergoing improvements and upgrades. There is an evolution of state of health monitoring to a predictive maintenance. Beyond analysing and estimating the life cycle of each station and its components, a continuous monitoring of the state of health of the various components can lead to identification of poor performance and aid predicting future failure. This assessment requires a comprehensive failure analysis. In particular, presentation O4.4-248 focused on the monitoring of the radionuclide systems. P4.4-477 explains a new paradigm for long term global network operation by taking measures for decreasing the operational costs by enhancing regional and local capabilities. A similar approach was taken in Australia for optimizing the performance, even for remote stations (P4.4-545).

Given the heterogeneity of the stations, for each of them a risk analysis is required, this was stressed during the oral presentation O4.4-742. Such analysis provides support for sustainment planning, with its corresponding uncertainty.

Station performance seems correlated with station or local operator preparation and commitment. Therefore, continuous station operator training should be considered in the sustainment plans.

The auxiliary stations consist of one third of the IMS network (presentation O4.4-747). These stations are not financially supported by the PTS, relying on the support of the host country. Unfortunately, in some cases, the

level of support is not enough to keep the station up to the minimum required levels of data availability. Voluntary contributions have shown to be a way to bring stations back to the required levels of operation. However, other innovative options should be explored to sustain this set of stations.

T4.5 On-Site Inspection Team Functionality

The session on On-Site Inspection Team Functionality was a new topic at SnT2023, which for the first time provided a forum to discuss the issue of OSI readiness on a system performance level. ITF, as described by its founding authors (O4.5-301), is the concept of operations that guides an OSI in the field, ensuring that inspection activities are based on an information led search logic in the quest to characterize and narrow down a search area that could potentially start at 1000 square kilometres.

The session comprised 12 e-posters and four oral presentations. Submissions and presentations categorized in this topic covered two overarching themes, the challenges and difficulties intrinsic to the successful conduct of an OSI using ITF and the opportunities and capabilities to overcome these challenges provided by emerging technologies and novel processes.

The introductive oral presentation provided a historical retrospective of the development of the ITF concept and explained the pillars that converted ITF into the concept of operations for an OSI. ITF is expected to successfully guide the inspection team during the conduct of an OSI once the Treaty enters into force. The concept forms the backbone of the inspector training programme and relevant tools such as GIMO to deliver the ITF logic, decision and operational cycles.

With the next IFE host country having been selected, possible challenges for conducting IFE25 in tropical regions are realistic. An oral presentation on an OSI challenge, with timely relevance to the upcoming IFE25, was the complexities of conducting an OSI in a tropical rainforest environment (O4.5-088). The speaker pointed out several environmental factors that can affect time critical signatures of an underground nuclear explosion, such as torrential rains and the jungle canopy. Similarly, an e-poster on field tests in mountainous environments (P4.5-303) listed technical and operational challenges in conducting OSIs in alpine settings.

In the practical scenarios, an OSI could be conducted in a place potentially with radiation hazards. Both OSI training courses and IFEs should take into consideration such conditions to safeguard inspection team health and safety and to build up the inspection team operational capacity for the real cases. The Chernobyl and Fukushima accidents have shown that the so-called 'co-expertise' process is an effective lever for empowering the affected people in order to give them the means to make informed decisions concerning their own protection. O4.5-275 described how the experience of co-expertise, which was recommended by the International Commission on Radiological Protection, can be a model to train the inspection team and the inspected State Party in order to solve their concerns about the consequences of radiological contamination in the inspection area.

O4.5-768 highlighted the various instances of GIMO developed to cater for requirements at the Operations Support Centre, the base of operations, the inspection area including the laboratory, as well as data classification status. The GIMO platform facilitates the implementation of OSI search logic by providing the framework and tools to meet the requirements of inspection team and field team functionalities, and data flow.

The importance of training was emphasized by presenters and the audience, with an e-poster on optimization of digital and remote learning in conjunction with face to face training (P4.5-879) and the development of

an airborne simulator used to train surrogate inspectors in different airborne equipment configurations (P4.5-648). The e-poster P4.5-629, proposed an information led ITF and field team functionality concept. P4.5-771 brought together information about samples into one application through data flows while maintaining chain of custody of samples during an OSI. P4.5-128 proposed a solution to radiation protection and radiation monitoring for an OSI, especially a lead-free radiation protection clothing option for the inspection team. P4.5-429 introduced a software application (Equipment and Instrumentation Management for OSI), physical devices and procedures to facilitate the calibration, maintenance and protection of deployable OSI equipment. Methodology, positioning and navigation of the inspection team, team building and health and safety issues were discussed respectively by P4.5-202, P4.5-039, P4.5-040, P4.5-627 and P4.5-786.

Theme 5: CTBT in a Global Context

The CTBTO verification system exists within the broader context of international organizations, global policymaking and international collaboration as well as public awareness and outreach. This theme explores lessons learned from other arms control agreements and arrangements and from relationships within the broader context as they relate to the CTBT and nuclear explosion monitoring. Advances in science and technology can drive progress in advising on policies and solutions based on data and evidence and can impact confidence building. This theme explores applications of verification technologies and identifies innovative solutions for change within the framework of the CTBT as well as other relevant agreements and arrangements. Science and technology play a key role in capacity building and regional empowerment. 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, if approved by the Commission, also serve synergies with global challenges and be used for civil applications, such as nuclear and radiological emergency preparedness and tsunami early warning. To ensure 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 through a broad range of outreach initiatives and science communication.

T5.1 CTBT Science and Technology Policy

Theme 5.1 focused on the interplay of science, technology and policy. Scholars and scientists discussed policy gaps and opportunities concerning the nuclear weapons testing ban, considering historical, institutional and socio-economic factors. Key highlights of the policy component of the SnT2023 conference revealed insights on knowledge governance of nuclear weapons testing, public engagement, the Treaty, and lastly, potential approaches to facilitate entry into force of the CTBT.

Strengthening knowledge on CTBT universalization:

Strengthening understanding and universalization of the CTBT has become increasingly paramount, as evidenced by both its role in broader international discussions and specific national contexts (P5.1-037 and P5.1-373).

The significance of the CTBT was highlighted during discussions on its peaceful implications for nations such as Iran where the author of O5.1-391 placed it as a potential diplomatic solution amidst challenging sanctions. Furthermore, the importance of science, technology and diplomatic synergy in the CTBT context was reinforced in O5.1-597 where emphasis was placed on the unique role of the CTBTO in international nuclear architecture and how the CTBTO can lead to advance nuclear non-proliferation.

This alignment between science and diplomacy, combined with the socio-political nuclear

constituencies, finds resonance in the study on India in O5.1-208. The research underscores the need for engaging a broader audience, bridging the gap between technical-scientific communities and the general public, as well as paralleling the initial call for a diversified nuclear constituency.

Across these discussions, what remains evident is the global emphasis on expanding knowledge boundaries and engaging various stakeholders, from international scholars to the general public, in the discourse on nuclear policies and technologies. This collective effort aims to strengthen the comprehension of the CTBT to achieve universalization.

Public engagement in nuclear science conversations:
Public participation in nuclear science discourse has increasingly been registered owing to pivotal events such as the Nagasaki and Hiroshima bombings, the Fukushima disaster and incidents like Kalpakkam which was detailed with respect to India's response to nuclear technology post-Fukushima. This rising awareness and participation, evident in protests in cities in India like Kudankulam and Jaitapure post-Fukushima, showcases a collective consciousness imprinted by past nuclear events.

In this context, the CTBTO emerges as a linchpin. An author highlighted the contrasting effects of sanctions on Iran with the potential benefits of CTBT ratification, emphasizing a more sustainable solution to nuclear challenges. Moreover, discussions that took place during the T5.1 oral session placed the CTBTO at a pivotal juncture of science, diplomacy and technology. These presentations collectively spotlight the urgent necessity for a multifaceted dialogue, combining both technical insights and public sentiments, to steer global efforts towards nuclear safety and non-proliferation.

New audiences may benefit from understanding the realities of nuclear weapons testing, and the benefits of the Treaty, not only for its capabilities to detect nuclear tests but also for its civil and scientific applications (P5.1-589).

Approaches to facilitate entry into force of the CTBT:
The entry into force of the CTBT is integral to ensuring international peace and security. To further the understanding and implementation of the Treaty, it is crucial to raise awareness, especially amongst regional and domestic lawmakers. As the research on the Fukushima disaster reveals, public perceptions play a significant role in policy decisions related to nuclear matters. Thus, joint efforts, including statements that stress the legal obligation of States to abstain from nuclear testing, can further emphasize the significance of the CTBT, propelling it towards entry into force.

T5.2 Synergies with Global Challenges

With six oral presentations, the session focused on the synergies of CTBT technologies supporting global challenges, such as climate change science as well as tsunami warning. The state of science in climate change research and in tsunami warnings was covered in the session and specifically, how CTBT technologies and IMS data can support climate change monitoring, how the IMS data can contribute to tsunami warnings and how cooperation with other organizations can help achieve global climate change goals and early tsunami warning.

The authors and convenors expressed their thoughts on the use of IMS data and their experiences of the effect of climate change, as well as on the tsunami early warning system. They noted that continuous monitoring of climate change is essential, and that better climate monitoring and projections are needed. In addition, the data availability from the IMS network in real time is very useful for tsunami related warning systems. CTBTO technologies and data can play a key role in these. The current use and future applications of CTBTO data and technologies were discussed, as well as how cooperation with other organizations can help to achieve the global challenges.

IMS data play a vital role in monitoring nuclear explosions (O5.2-465). However, they also have the potential to contribute to climate monitoring and climate change research and can improve our understanding and response to climate change. IMS data contribute to these activities by detecting atmospheric events, verifying emission reduction efforts, monitoring the oceans, improving climate modelling, studying long term trends and fostering collaboration. By raising awareness and promoting the peaceful use of IMS data for climate studies, support can be built for this important cause while contributing to the global effort to achieve universalization and entry into force of the CTBT.

The correlation between climate change and global security was presented in O5.2-455 and prospective contributions the CTBTO can make to the issue were sketched out. Furthermore, analysis of prospects for using IMS data for confidence building measures for the non-signatory States was also discussed.

Data from the six IMS seismic stations, together with local data from the extensive monitoring network, provided an early warning to the public just after the occurrence of the M7.5 earthquake (O5.2-854) located in the Flores Sea in Indonesia on 14 December 2021. This example once again reinforces the use of IMS data in the context of preventing the impact of natural hazards.

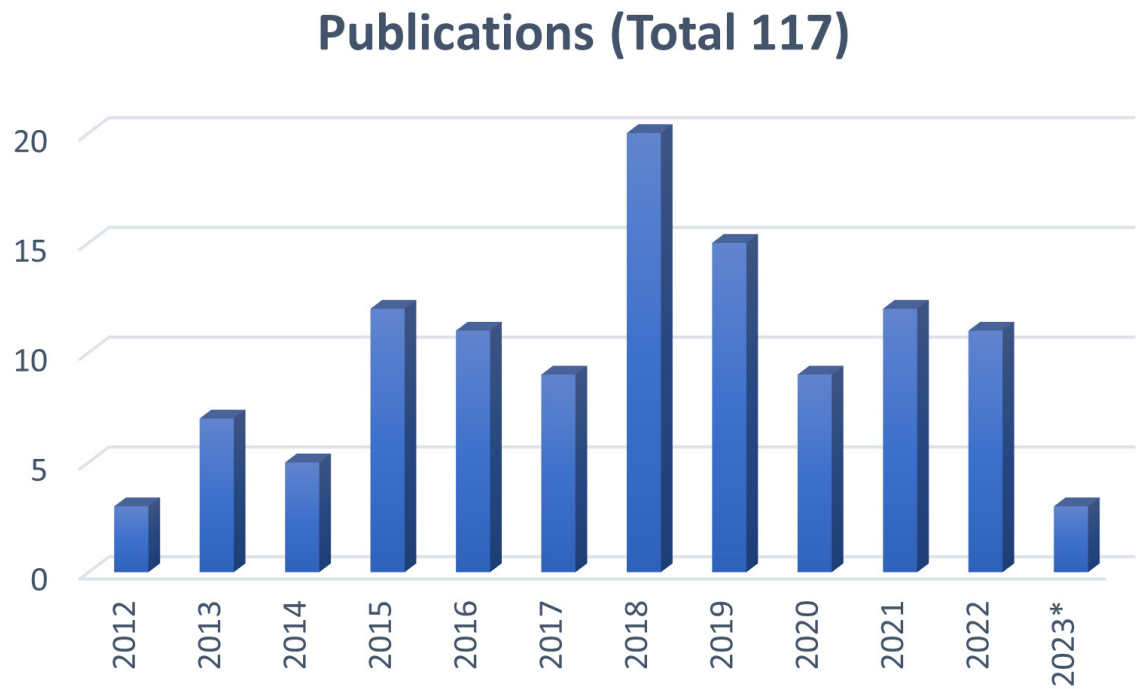
Current early warning systems rely on earthquake magnitude, which primarily results in more than three-quarters of alarms being false. To reduce false alerts, a complementary real time tsunami early warning system methodology has been developed (O5.2-076). The methodology is based on the analysis of acoustic signals under the effects of gravity, acoustic gravity waves (AGW), which are generated by a tsunami. AGWs carry source information, which is recorded by remote hydrophones. The analysis of these recordings, in real time, requires solving both inverse and direct problems, which are the main strength of the proposed alert methodology. Various theories and applications of AGW, both fundamental and applied, were discussed, as well as how the analysis of IMS hydrophone data contributed to the development of new mathematical models. Attention will focus on the real time tsunami early warning system methodology, which has been further developed into operational software.

Through close collaboration with the CTBTO, the Civil Protection Authority of Timor-Leste aims to leverage the predictive analytics capability of the IMS to issue timely alerts to save more lives (O5.2-376).

The geographical location of Bangladesh is at the northernmost part of the Bay of Bengal. Tectonically, the region is at the junction of the Indian and the Eurasian plate, making it an active tectonic zone (O5.2-605). Therefore, there is a possibility of an earthquake in the ocean occurring in any part of the region, which could generate a tsunami. Bangladesh hosts IMS station AS7 and an NDC since 2011 and was therefore invited to establish a tsunami warning agreement with the CTBTO, following the defined and agreed procedure between the PTS and the States Signatories. However, only tsunami warning centres recognized by the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO) can enter into a tsunami warning agreement, which in this case is the Bangladesh Meteorological Department.

The 24 e-posters of T5.2 covered a wide range of subjects related to disasters and hazards, including understanding the basic science, monitoring, preparedness and resilience, thus covering both physical and social sciences. As in the oral session, tsunami early warning was a significant focus, as were the sources of a tsunami – seismic and volcanic activity – to provide better and earlier warning. Such studies have been undertaken in many countries with the potential of being impacted by these hazards (P5.2-045, P5.2-048, P5.2-130, P5.2-555 and P5.2-762). Seismic and volcano monitoring were considered in several

presentations (P5.2-058, P5.2-209, P5.2-478, P5.2-669 and P5.2-765), and one e-poster presented an enhanced the seismic network in central Asia and the Caucasus (P5.2-464). Links between climate change and tsunamis were presented in P5.2-008 and P5.2-106. IMS data were shown to be useful for deducing the thermal field associated with a volcano in the Russian Federation (P5.2-162), studying avalanching glaciers in Italy (P5.2-720) and studying the threat to aviation from volcanic ash in Indonesia (P5.2-611). Radionuclides, especially resulting from the Fukushima nuclear power plant accident, have been used to study the effect of the monsoon in Thailand (P5.2-143) and for many other scientific applications including ATM (P5.2-296 and P5.2-321). Symbiosis between the IMS and other monitoring systems was highlighted in several presentations (P5.2-142, P5.2-288 and P5.2-330). There were presentations considering the interconnectedness between the CTBT and the Nuclear Non-Proliferation Treaty (P5.2-807), and the role of the CTBTO in the 2021-2030 United Nations Decade of Ocean Science for Sustainable Development (P5.2-876).



P5.2-288: Evolution of the number of publications related to vDEC contracts from 2012 to May 2023.

T5.3 Regional Empowerment

With five oral presentations (one video pre-recorded) and 19 e-posters, the session focused on capacity building and training activities, on technical assistance to NDCs, on networking between institutions in various regions, on cooperation among NDCs and on multilingualism. The sessions featured contributions from 19 NDCs located in five Treaty regions, it also included presentations by relevant authors from the PTS. Overall the session demonstrated the wide range of activities carried out by NDCs and the positive impact of the PTS capacity building actions over the years.

The authors presented their experiences on the use of IMS data and IDC products as part of their day to day activities. Many of them highlighted the progress achieved by their NDCs thanks to PTS projects such as the NDC in a box initiative. The ongoing use and future applications of IMS data and IDC products were covered, as well as how cooperation with other NDCs and institutions can help to strengthen NDCs, national capabilities and further advance universalization of the CTBT.

IMS data help to study earthquakes in West

Africa (O5.3-227), which allow earthquake catalogues to be compiled in regions with limited instrumentation. Similar studies have been carried out in other regions of the world, such as the Caribbean region and South East Asia, where IMS data and IDC products complement observations from national networks with the goal to increase earthquake monitoring capabilities and raise awareness of the potentially rising seismic activity in those areas (P5.3-027, P5.3-057, P5.3-156, P5.3-550, P5.3-827 and P5.3-851).

Solutions provided by the IDC in recent years were emphasized by a majority of the presenting authors in this session. The toolbox to process and analyse IMS data and national waveform data with NDC in a box or the computational capabilities gained through the deployment of capacity building systems contribute to advance the technical abilities of NDCs (O5.3-265, P5.3-094, P5.3-422- and P5.3-451). These PTS projects were praised by authors, but also encouraged the PTS to pursue its effort to assist NDCs in building their capacities. The IDC reported on the achievements in recent years of its capacity building projects, thanks to regular funding from the PTS and from the European Union (P5.3-263).

Software made available through the NDC in a box project contributes to the advancement of NDCs for accessing and combining data from the IMS and other national network; it enables researchers to analyse the data and compare their results with IDC products and it also provides the opportunity to assess the quality of IMS data or carry out comparisons with data from other networks (P5.3-609), which helps to increase geographical coverage. While a large proportion of the presentations in T5.3 focused on seismic, hydroacoustic and infrasound technologies, several studies also provided insights into the importance of IMS data and NDC in a box capabilities for the analysis of radionuclide data, both particulate and noble gas (P5.3-492). A presentation further highlighted the link between capacity building projects for the technology and the operation of radionuclide stations in Latin America (O5.3-404). The NDCs4All initiative kicked off by the Executive Secretary in 2022 was also prominently mentioned in a number of presentations and in particular in the context of future activities of the PTS with NDCs (P5.3-291 and P5.3-359).

One of the main highlights of the session was the organization of training and workshops by the PTS with participants from a large number of NDCs (O5.3-177, O5.3-684, P5.3-107, P5.3-156 and P5.3-368). Such opportunities are seen as vital for the continuous progress of NDCs in advancing their capabilities, but also in providing them with solutions to create bridges between them and cooperate with each other on technical projects (O5.3-177 and P5.3-368). Authors further encouraged the PTS, NDCs and national authorities to go beyond the traditional split of technical training and diplomacy symposium by bringing all relevant stakeholders of the CTBT together as is the case every two years during the SnT conferences.

The session was also an opportunity to go beyond the traditional capacity building projects and spinoffs provided by the PTS. Several NDCs and institutions presented their national initiative to advance their technical capabilities (P5.3-081, P5.3-204 and P5.3-666). These national efforts demonstrated the willingness of NDCs to continue strengthening their abilities to increase their understanding of IMS data and IDC products and their role in the verification regime. It also showcases the importance for these authors to share their progress with the PTS and with other NDCs to illustrate their commitment but also to inspire other NDCs to do the same. Great achievements based on software solutions widely used in institutions worldwide, such as Antelope, SeisComP3 or SEISAN were presented, which demonstrates the technical know-how of several NDCs. This progress demonstrated what can be achieved with the SEISAN package and using the SeedLink Service provided by the PTS to build an automatic seismic event detection solution using IMS data (P5.3-866).

T5.4 Outreach

In the CTBT's global efforts for entry into force and universalization, women should be empowered and included to champion the CTBT, ensuring diverse voices and gender equality in the decision making process. Inclusivity must be fostered in STEM for those with disabilities and engage youth in shaping a nuclear free world for generations to come (O5.4-542, P5.4-034, P5.4-075, P5.4-136 and P5.4-556).

Cooperation between the CTBTO and Africa, involving the African Union and the African Commission on Nuclear Energy, African leadership and training programmes, can enhance nuclear disarmament. NDCs should promote awareness locally and mentor young scientists. The geopolitical importance of the Middle East and North Africa calls for media attention on the vital role of the CTBTO in nuclear issues. India is showing a shift towards denuclearization, requiring a rehabilitation commission, data collection, community involvement and the active role of the media in reshaping the nuclear discourse for social progress (O5.4-159, P5.4-418, P5.4-585, P5.4-427 and P5.4-010).

Education is key to shaping a responsible and engaged future generation in nuclear discussions, promoting public awareness, equity, inclusion and creating a global network of informed individuals. Highlighting the civil and scientific applications of verification technologies can attract more young people to these fields. Scientists and educators should communicate these advancements widely, fostering greater awareness among the public and decisionmakers, ultimately contributing to the entry into force of the CTBT (O5.4-590, P5.4-221 and P5.4-511).

Effective outreach and communication strategies, including strategic communication, citizen engagement and the use of technology, are essential to raise global awareness about the negative impacts of nuclear weapons and promote the CTBT. Additionally, leveraging the peace media theory, organizing debates, and expanding outreach through various media channels, web sites and social platforms, along with updating and broadening the list of influential personalities, are crucial steps in advancing the cause and building support for the Treaty (O5.4-399, P5.4-861, P5.4-824, P5.4-470 and P5.4-073).

P5.4-845 underscored the significance of interactive activities to educate individuals about the history of nuclear weapons and the CTBT, as well as the necessary actions to be taken in the present to facilitate the entry into force of the Treaty and its universalization, while also preparing them for future decisions in this critical endeavour.

5. Closing and Awards

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5.1. Closing Remarks from the Executive Secretary of the CTBTO Preparatory Commission

Excellencies, scientific experts, colleagues and friends,

As we now come to the end of SnT23, I have been thinking about what the reasonable measures of success are for a conference and what metrics of success we should have. For some of you, success for this meeting might be that 5000 sandwiches were successfully delivered and devoured, 3500 bottles of water, 12 338 glasses were cleaned and washed. For others, success might have been deploying nearly 1.4 kilometres of duct tape all around this venue. Others would want to marvel at 10.6 million pixels of projection, or the 78.34 tons of audio-visual equipment has been deployed in this place. So, let's all say thank you to the audio-visual team, the logistics people and the Hofburg team for what they have done to make this meeting a success.

But maybe closer to home for many of you is the number of people. We ended up with a little over 2000 registrations; an all-time high, an amazing number, with almost 150 countries represented. But accommodating that was not automatic, it did not happen on its own. We have had people working hard on the App support, on the registration support desk, as well as the security team, so let us thank them all for their efforts.

But there is more. We have listened to 100 oral presentations in different shapes and forms, seen 450 e-posters, and 29 exhibits: an amazing number. All of that was put together by the SnT programme coordination committee, in particular Martin Kalinowski and Pierrick Mialle and their team, who have done an amazing job. I have heard comments from so many participants about how wonderful the programme has been, and how well organized. We owe a great debt of gratitude to the team and the many people that supported them. But the person who headed all of those is our Director, Zeinabou Mindaoudou Souley. She is the executive lead for this whole SnT conference. Zeinabou, thank you so much for the great job.

But to me, the real measure of success actually goes one step further. When we bring so many people together - about 1500 technical people –the key measure of success is about the relationships formed, the collaborations that have been sparked, the ideas that have been generated, the technologies which are new and can be applied in all sorts of ways. That, to me, is the power of together and that is the measure of success. I look forward to seeing that roll-out as we move forward.
I want to share just a couple of programmatic highs. The first was the opening morning, when I was sitting down next to Abshir Omar Jama Huruse, the Minister of Foreign Affairs from Somalia. He leaned over to me from time to time through that morning session, marvelling that Somalia could be part of the CTBTO family. He then told us that they will sign, and they will ratify this Treaty. He is following through and issued instructions to New York to see the signature of the Treaty by Somalia. I wish they were here today to applaud them for their great achievement.
I loved the public panel session where we heard all about the Hunga Tonga-Hunga Haʻapai wai volcanic eruption. We heard about people from

different parts of the world that were looking at the same event through different lenses, different technologies, different experiences, different disciplines. We heard such an amazing story, of somebody getting up to feed their baby in the middle of the night in Alaska, hearing that volcanic eruption, and then later working through the physics and the science of that event. That was a great session, as was the one focusing on the Syrian-Türkiye earthquake.

We had four directors of the International Monitoring System Division: the very first, the second, and the last two. It was amazing to hear from them their decades of experience, their decades of commitment, from some that were here right at the start. A wonderful high point for me.

An unexpected high point for me was engagement with the next generation, with the Young Professionals Network's people, the CTBTO Youth Group, those that have been involved in our internship programme, those that have been involved in our mentoring programme. These young people are so keen about our Treaty. We often say that young people are full of passion and optimism implying that they have not got good ideas. They are not just full of passion and optimism: they do have lots of good ideas. To hear their views was so valuable, and that the platform was created here enabling that to take place was one of my programmatic highlights.
I want to finish with two most memorable moments. It came again from interacting with the next generation, the early career people. I wanted to share it with you because it is about the theme of the power of together. One of them was talking with a young person with a disability. This person gave me a gift. The gift was her perspective of what it is like to have a disability and to be at a conference like this, or at other places. She was very positive about how we have accommodated disability. But I wanted to share with you one thing she said. When you have a disability, you feel like you are always a burden to others to be able to accommodate your disability. Now, I know we never mean to sound like that. I would say "we can find a way to accommodate", but my subtext is still almost that this is a burden to be accommodated. It was so challenging to me to hear it from her eyes. That was one of my most memorable moments.

The last high point I want to finish with is again about a group of young people. This was really challenging to me because as you know I am white, I am Western, and I am in a position of power. I have all those things which are normally associated with privilege. I spoke to a group of people that are not male, not Western, do not speak English as a first language. I heard three different people on different occasions say: "I asked the question, do I belong here?". I thought to myself, you look so full-on confident, self-possessed, and yet inside you ask, "do I belong here?". Every one of them said they belong here. That is a tribute to all of you for making this such an inclusive, embracing community where so many people can feel they belong. Friends, you should give yourselves a round of applause, because, if we continue in this vein, the power of together will go with us as we move forward.

It is a pleasure to have hosted you at this Science and Technology 2023 conference, and I thank you for your contributions.
Thank you very much.

5.2. Concluding Remarks from Anne Strømmen Lycke, Chief Executive Officer, NORSAR

Firstly, let me thank the Executive Secretary and his team for organizing this remarkable conference! It has been a pleasure to be part of this extraordinary gathering of technical experts and scientists, observing the engagement and togetherness at work for the CTBT verification.
I am also pleased to see the concern and will to help protect the investments made in the system – be it the monitoring system, the technologies and the software. and not least the people involved.

We all received a strong reminder when we observed the Hunga Tonga volcanic eruption and its record reverberations around the globe. This event was the equivalent size of a large nuclear explosion. It will be the basis for studies and new knowledge for many years to come for waveform technologies thus providing deeper insights into the Earth's dynamics.

It goes without saying that the basis for waveform technologies is a well-functioning IMS and IDC with long lived stations and robust software solutions. In this regard, the engagement in IMS sustainment observed during this conference is promising.
Much effort is put into the making waveform methods and technologies better and many examples were presented this week. The increased focus on machine learning and artificial intelligence points towards more effective processing of large volumes of data, as well as more precise detection. The large databases and reviewed bulletins should be excellent tools for training the algorithms.

Detecting smaller explosions is also a challenge for the verification system and monitoring of the event detection threshold should be prioritized.

During the week I had the pleasure to meet younger scientists – always an engaging experience. To recruit and retain the best young technicians and scientists are important to secure the future of the Treaty, its de facto moratorium, its global acceptance and its entry into force. It was especially interesting to hear how States Signatories are building up their NDCs – some participating at an SnT conference for the first time! To be part of this mission makes for a meaningful career. In addition the possibility of using the data and the technologies for civil and scientific purposes may make a sound basis for retainment of people and contributions to society at large.

To sum up: SnT2023 was successful, invigorating and fun! Thank you again for organizing the event!

5.3. Concluding Remarks from Anders Ringbom, Research Director, Swedish Defence Research Agency

Thank you. I would like to go through this by loosely following the verification process from source term – dispersion – measurement – analysis, and try to discuss what are, in my view, the biggest improvements and opportunities, and what are the biggest challenges.

Starting with the nuclear explosion itself, in terms of understanding the released isotopic composition and time profile, it is my impression that work is really advancing in this area, and several contributions at SnT2023 showed that. There are several groups that are working on modelling the release mechanisms in an underground nuclear explosion. This is a very complex problem, but the models are becoming more and more advanced. This has considerable implications both for OSI and IMS. For example, I am really hoping that the modelling tool that was presented by the Commissariat à l'énergie atomique et aux énergies alternatives (can be available for a wider community. It looks really promising.

To understand the source term, historical data is of course very valuable. In the case of radionuclides the amount of such data is not overwhelming. Therefore, I really appreciate the effort presented atSnT2023 where almost 100 publications containing such data were compiled which really helps the NDCs in their work.

The low yield nuclear monitoring programme that was presented at this conference, including an experimental test bed at Nevada National Security Site with more than 1000 sensors to capture a number of different signatures, really promises to give new insights with respect to the source term as well as for other parts of the verification regime, such as the dispersion of radionuclides.

The work in atmospheric dispersion of radionuclides is also advancing; and a very important but challenging problem is the uncertainties of the atmospheric transport models. The work on ensemble modelling shown here gives the opportunity to quantify the ever varying weather uncertainty. This could be of tremendous help to the NDCs to judge the confidence in their assessments. Moving to IMS measurements, we have heard a lot about the next generation noble gas systems. These have actually been around for a number of years, and I am happy to note that the roll-out is ongoing. As shown in several contributions this week, these new systems will give IMS new, sharper tools, both with respect to time resolution and sensitivity. This helps to identify new background sources and to isolate a nuclear explosion signal.

This brings me to a couple of challenges. One has already been mentioned by Anne Strømmen Lycke, sustainment. This is also an issue for the radionuclide systems. One aspect of this is caused by the fact that the IMS uses a very specialized technology, not used by many others, which means that the market is small, which implies challenges to both the user and the equipment supplier. For IMS sustainment, new approaches towards predictive maintenance should be envisioned, for example, monitoring state of health parameters using machine learning.

Another big challenge, where much is being done, but a lot of work still remains to be done, is the radionuclide background. This is true both for radioxenon and aerosols. This challenge can and must be addressed in several different ways: mapping potential sources, by information gathering as well as background measurement campaigns; measuring releases at the source, as is done in the STAX project; and reduce the releases by installing abatement equipment. It would be great to see more facilities install such systems.
In addition, SnT2023 has shown that new background sources are coming, including new isotope production facilities, neutron spallation sources and molten salt reactors. New isotopes, not considered earlier, can be emitted, some of them with ratios ending up in the nuclear explosion domain. It is still a long way to go until we are able to identify all background contributions in all measurements. Again, also do not forget that there are many unidentified aerosol detections.

An opportunity in the area of measurement that has been growing over the last few years is the next generation aerosol systems, for instance by using electrostatic sampling. Also, for xenon and argon further development is ongoing, including new detectors with better energy resolution. Here we should consider which way is the best way to go. What time resolution is really necessary given ATM uncertainty? How sensitive does the system really need to be? In addition, the cost aspect should be taken into account. Avery fancy, very expensive detector can always be built. And do not forget the network perspective; it is the network that is the machine, not the individual systems.

This brings me to the last part: analysis of radionuclide data. Here the trend is clear, however, some work might remain to improve the analysis of spectra, but more and more work is done to create event association schemes. This is a challenging problem. Which detections belongs to a particular source? Which samples do I select for my location analysis? We have seen here at SnT2023 how this problem can be addressed in several different ways, including machine learning. The location techniques are constantly evolving as shown at this conference. Here we have another challenge: can we create a standard way for the NDCs to locate a source? Right now, much manual tweaking is required. It is a difficult problem, in particular if the source is complex. However, I have no doubt that this community has the capability to advance this further.

5.4. Concluding Remarks from Dorice Seif, Tanzania Atomic Energy Commission

My presentation focused on three questions addressed as follows.

Let me start with the question, what is the biggest opportunity for future developments that I witnessed at this conference? At this conference, 11 internationally active professional societies with strong links to the CTBT were introduced. They give examples of the tremendous opportunities available for collaboration with the CTBTO and the international expert community involved in CTBT matters.

The second question was, what is the most visible achievement since SnT2021? SnT2023 gave voice and visibility and tasks to the young generation and early career scientists. Different from previous conferences, the young professionals/generation did not have a parallel programme but were completely integrated into the main programme and were invited to give presentations and to act as panellists. This enhanced inclusiveness and results in the broadening of ideas and breaking out of patterns of traditional thinking. I very much appreciate this. One message shared by speakers from the professional societies and other panellists is to seek more opportunities to offer training, scholarships and other means to support the next generation of experts to grow into the leaders of the future.

This conference sets an example of inclusiveness by providing accessibility to women, the young generation from developing and developed countries, people with disabilities and other underprivileged groups. A good example of this is the pilot mentoring programme for early career women in STEM. Eight out of 12 mentees were given the opportunity to attend the OSI regional training course in Slovakia this year. Officially, the mentees were brought in as additional observers, but they participated fully in the activities. During the training course, half of the field team leaders were women, all mentees from the mentoring programme. The reason they were not chosen as the field team leaders was not because they were women but simply because of their capabilities to act as leaders. Currently, four mentees have been officially nominated and accepted attendance at the OSI Linear Training Programme.

Now, I turn to the last question, what is the biggest opportunity from new scientific developments shared at this conference for the preparation of IFE25? In general, deployment of artificial intelligence, virtual reality and modelling are the biggest opportunities in new scientific developments. SnT2023 showcased new opportunities for equipment development and testing, and training of OSI surrogate inspectors. We experienced this through virtual reality tools including the realistic OSI airborne simulator in a helicopter frame. Other OSI-related highlights include contributions focusing on the potential of ground and near surface remotely controlled measurement platforms during an OSI and we saw first-hand a robotic dog with relevant sensors in action. The importance of exercising OSI equipment and procedures was addressed and the challenges of operating in environments such as the tropics were emphasized.

Thank you very much for your attention.

5.5. Closing Remarks from Zeinabou Mindaoudou Souley, SnT2023 Project Executive, CTBTO Preparatory Commission

If you did not receive an award, I would like to assure you that you all deserve appreciation and thanks for your active contribution. We all are awarded by coming together and exchanging the latest information on science and technology in the context of the CTBT, by inspiring each other, by making and renewing contacts we will stay in touch.

Let me add to all the praise and thanks that the Executive Secretary had expressed. First, I thank the Executive Secretary Mr Robert Floyd, for assigning me as Project Executive. I want to commend his leadership, as we would not achieve anything without his support.

Martin Kalinowski and Pierrick Mialle did an extraordinary job. I thank them for their patience and perseverance. There was a wonderful team behind us. We had many excellent leaders and agile teams of the many different tasks with highly dedicated staff across all Divisions of the CTBTO who prepared the event for more than one year. I should not forget to extend my gratitude to the outstanding members of the SnT2023 Programme Coordination Committee. We also sourced out a large amount of work to contractors. This week, a huge team is working behind the scenes running the event effectively. I thank you all for your commitment and professionalism.

The whole event would be nothing without you as participants. I want to thank all participants for joining online and in person at the Hofburg and for making your active contributions: scientists, technologists, academics, delegates of States and students. I am especially happy to see more and more young female experts in the STEM areas. I would like to also mention station operators and NDC staff. In addition, we have representatives of science diplomacy, science advisory, media and advocacy attending this conference.

Participants are very happy and shared positive thoughts: we can leave COVID-19 behind - our science festival is back! SnT2023 is a demonstration of the growing interest in this conference and a clear demonstration that it is more successful than ever. I would like to ask all participants (online and in person) to kindly provide us with feedback because it will allow us to improve our work. On Monday, all participants will receive a link to the survey on the event platform. I wish all those who travelled to Vienna a safe trip back home.

5.6. Awards

Following the final reflections and summaries, the SnT2023 conference concluded with the awards ceremony. The European Union Star award was presented by Ambassador Stephan Klement, Head of the Delegation of the European Union to the International Organisations in Vienna, the Early Career Scientist award, Best Oral Presentation and three Best e-Poster Presentation awards, were presented by a PTS Director. Three out of the six awardees are early career scientists. All participants were invited to vote for the oral and e-poster presentations which they liked.

Panel discussions and invited talks were not considered for awards. Multiple votes were possible but only one per presentation was accepted. Overall over 1000 votes were given to a large number of presentations. The CTBTO allocated the awards to the presentations that had the largest number of votes and fulfilled the award criteria while observing the priority of awards which was also applied to the sequence of award presentations.

European Union Star Award: P3.5-524 - Seismic Discrimination between Nuclear Explosions and Natural Earthquakes Using Multi-Machine Learning Approaches presented by Ms Shimaa Elkhouly (*National Research Institute of Astronomy and Geophysics, Egypt*)

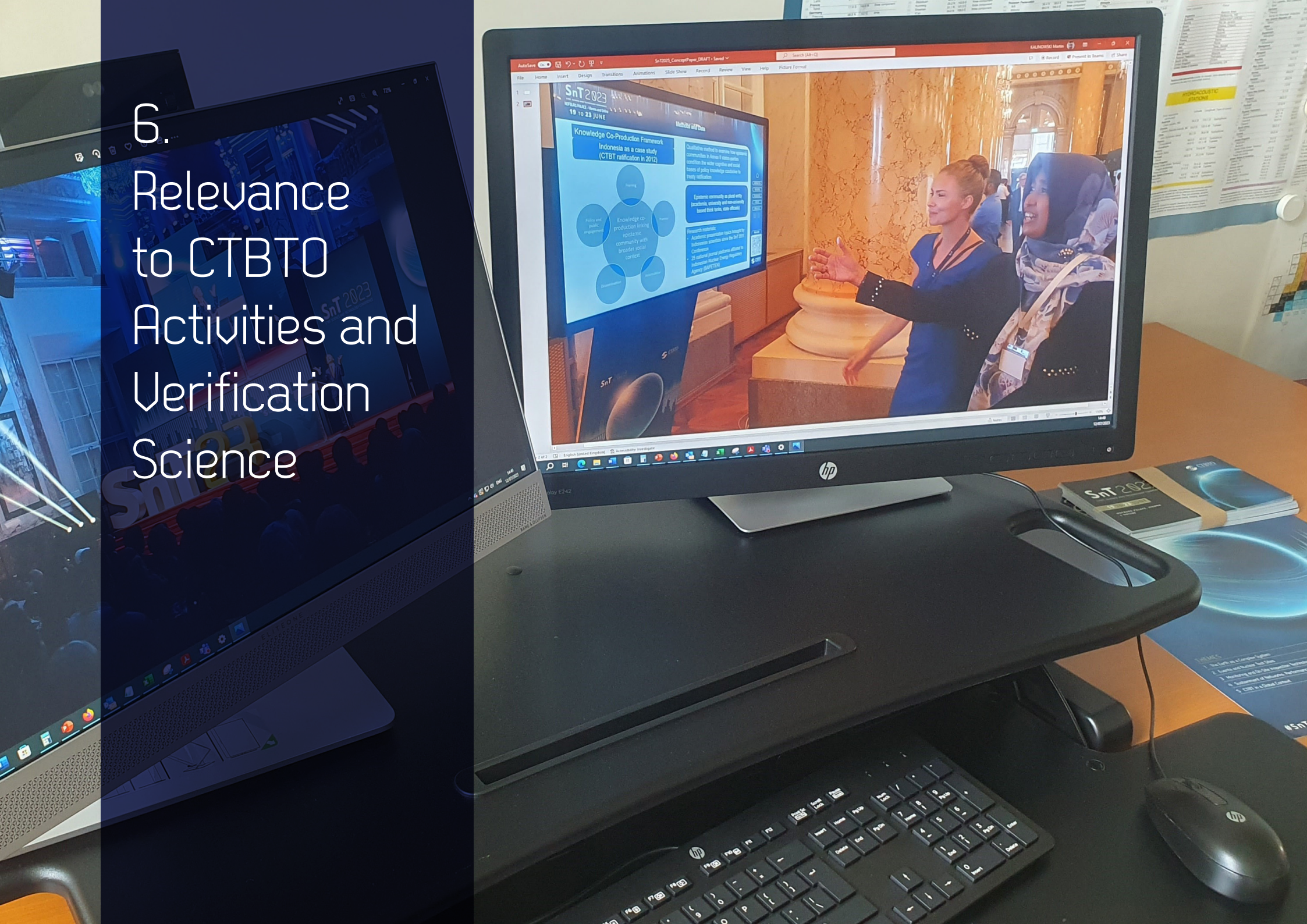
Early Career Scientist Award: P5.1-037 - Efforts Challenges and Way Forward for the CTBT Entering into Force presented by Mr Abdulmajeed Ibrahim (*Nigerian Nuclear Research Authority, Nigeria*)

Best Oral Presentation Award: O1.4-514 - International Monitoring System Observations of Infrasound and Acoustic Gravity Waves Produced by the January 2022 Volcanic Eruption of Hunga, Tonga: A Global Analysis presented by Mr Julien Vergoz (*Commissariat à l'énergie atomique et aux énergies alternatives, France*)

Best E-Poster Presentation Awards:
P1.2-394 - Seismotectonic Setting and Coulomb's Stress Change for Earthquakes in Aswan, Egypt presented by Ms Mona Abdelazim Abdallah Metwally (*National Research Institute of Astronomy and Geophysics, Egypt)*

P3.4-513 - Synergy Between Comprehensive Nuclear-Test-Ban Treaty Technologies and National Technical Means presented by Ms Mariem Agrebi (*University of Vienna, Austria*)
P5.3-422 - Capacity Building and Technical Assistance Cooperation in Jordan National Data Centre presented by Mr Murad Alhomaimat (*Jordan Seismological Observatory, Jordan*)

6. Relevance to CTBTO Activities and Verification Science



6. Relevance to CTBTO Activities and Verification Science

6.1. Measurement Technologies

6.1.1 Sensors and Networks

One area of ongoing research in sensor technology has the goal to increase the sensitivity or robustness of IMS stations, IMS laboratories or OSI field systems. Incremental change in equipment brought about through practical experience is typical in the development of operational systems but step changes are also possible when new methods for acquiring inspection data are developed. This point was highlighted during Panel Pa2.4 when gamma imager technology was presented. Presentations relating to the miniaturization and portability of sensors are particularly relevant to OSI, since there is a general effort to minimize the physical footprint and operational requirements of a deployment from headquarters to the base of operations and from there to the field to perform inspection activities (P3.3-362 and P3.3-471).

As part of the SnT2023 Exhibition, Leica Geosystems demonstrated the application of a robotic remotely controlled ground based vehicle with the capability to 'walk' sideways as well as up and down steps. For the event, the platform carried a payload comprising the Leica laser scanner. Unmanned and remotely controlled platforms in general featured in various e-posters and presentations (O3.3-863, P3.3-224 and P3.3-308). Remotely controlled ground penetrating radar robots, based on the commercial off the shelf ground penetrating radar system, might show their practical use when hazard challenging conditions apply during OSI activities. Automatic, wide ranging and reliable subsurface object detections can be expected whereas the adaptability of such systems to OSI scenarios needs further customization and optimization, also in the light of a concept of operations demonstration during future IFEs and OSI training courses (P3.3-089). These contributions, amongst other information, will contribute to a project assessing the relative merits of remotely controlled platforms that is part of the OSI Programme of Work for 2022-2023.

To identify the next generation of equipment to be deployed at IMS stations for recapitalizations and station upgrades, the PTS needs to keep abreast of the latest developments in sensors. The performance of new generation noble gas systems continues to be revealed after the success of the SAUNA III system, which was presented at the previous SnT conference. A summary of radioxenon detections with the SPALAX-New Generation system concludes that the number of detections is drastically increased (P2.4-459). The Xenon International system is the third one that passed the systems acceptance testing (P3.2-843 and O2.4-497). The twofold increase in sampling frequency with the Xenon International system enhances the localization capability (P2.4-818).
For radionuclide technology, advances in sensor technology are in essence driven by improvements in sample collection, sample processing and detection technology (sensitivity or resolution).

Improved collection of particulate aerosol samples both for IMS and OSI applications is expected through the adoption of electrostatic collection technology (P3.2-746 and P3.2-829). Electrostatic collection achieves collection rates comparable to current IMS and OSI systems at much reduced power consumption. A prototype electrostatic collection system for the RASA system for IMS station application is planned to be deployed in the near future (P3.2-268).

The reliable and efficient collection of xenon from air is fundamental for the operation of xenon sampling units in the IMS and for OSI. There is ongoing research into the behaviour of silver exchanged (doped) zeolites, which are already used in some commercial noble gas systems, as well as possible new materials which may increase efficiency and reliability

for xenon collection and may promise improved separation of xenon from other gases (P3.2-233, P3.2-803 and P3.2-877).

Research is being conducted on improved detectors and detector systems for radiation detectors with the aim to provide improved performance in regard to detection and identification of Treaty-relevant radionuclides, both particulate and noble gas (O3.2-381, O3.2-345, O3.2-218, P3.2-371, P3.2-382, P3.2-392, P3.2-463, P3.2-512 and P3.2-599). For particulate radionuclide stations and laboratories, a significant increase in sensitivity to a number of Treaty-relevant radionuclides can be demonstrated by the application of coincidence measurement techniques (P3.2-662). Coincidence techniques have been shown to provide high sensitivity and selectivity for those radionuclides having coincident gamma or X ray emissions.

Several e-posters in session T3.1 addressed the design and assessment of new geophysical sensing techniques and sensors. Efforts in seismometer design focused on very large band sensors with very low self-noise and high resolution (P3.1-595) through promising innovations such as the integration of optical transducers (P3.1-313, P3.1-333 and P3.1-788). For hydroacoustic technology, other e-posters focused on assessing and repurposing subsea cables for geophysical observations by integrating environmental sensors (P3.1-280 and P3.1-797).

For OSI and for the IMS network the agility of the equipment becomes more important, to ensure faster reaction. Portable and flexible solar charging packs allow an increase in the power production of equipment and stations. They are extremely portable and quick to deploy, with the power capacity providing an emergency charging supply to portable equipment during field operations. Lighter and more portable VSAT antennas, that can be deployed on vehicles, are easier to install, while enhancing transmission bandwidth and ensuring less data latency. Optical fibre geophone arrays are tested to provide solutions adaptable to field exercises to enhance the performance of the next generation of active seismic surveys (P4.2-029 and P4.2-261).

6.1.2 Quality Assurance

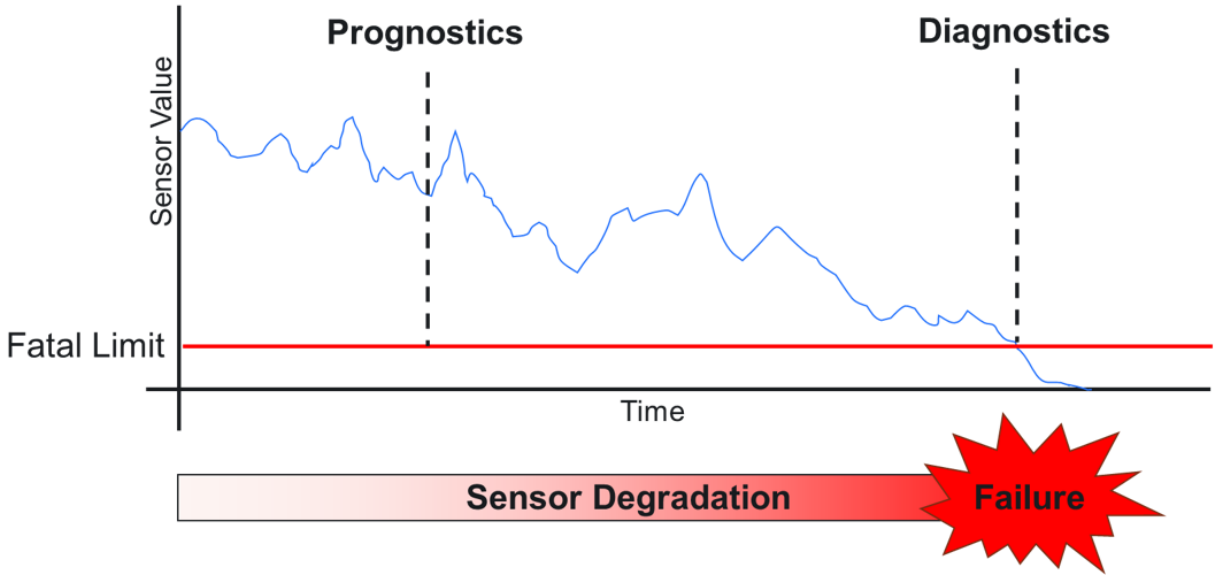
Substantial progress has been made by the scientific and metrology communities over the past few years in characterizing the response of infrasound sensors in laboratories, targeting traceability to the SI (as illustrated in O3.1-676, P3.1-724, P3.1-646 and P3.1-671 presentations, and during a dedicated workshop). The benefits of further collaboration with the metrology community and linking IMS monitoring within the SI include (I2.8-912): greater take-up of measurement traceability, mutual acceptance of global calibration capability, better understanding of uncertainty in measured quantities (e.g. amplitude and phase responses), better characterization of the susceptibility of sensors to environment and installation conditions, enhanced interoperability stemming from performance based specifications for equipment and common operating procedures. Such benefits impact all stages from equipment specification and type approval, through to on-site calibration. Implementation of the strategy for infrasound is ongoing with several elements still to be implemented, including dissemination of the tools and training of stakeholders, roll-out of systems and formalization of the quality framework.

While laboratory calibration methods are in development, work is also directed by the community at developing and assessing methods for on-site calibration. This was illustrated in O3.1-698, which focused on the determination of the frequency response of seismic and infrasound IMS station sensors using an on-site calibration approach. O4.1-051 illustrated how on-site infrasound calibration results could be utilized to improve the estimation of the wave parameter. This work is well aligned with the current developments of the CalxPy software undertaken by the PTS for the calibration of IMS stations (P3.1-578). Furthermore, the conference demonstrates

that there is scope for IMS seismic operations to build on existing best practices in national networks, and recent developments and successes in quality assurance for IMS infrasound measurements – adopting a similar approach, but adapted for the specific technical and logistical challenges, which are not insignificant (Pa2.8). National laboratories show increased interest to apply metrology to seismic sensors (P3.1-172 and P3.1-618), and to identify the current challenges and opportunities of the existing electrical calibration method, for instance its susceptibility to temperature (P3.1-860). Better articulation and assessment of seismic system performance requirements (e.g. digitizer and sensor specifications and type approval to maximize equipment compatibility and revised and improved calibration processes) would be helpful in managing the diversity of legacy equipment under use in the IMS, and in defining future performance requirements for equipment and systems deployed in the IMS network.

6.1.3 Performance Monitoring, Maintenance and Sustainment

The IMS network proved its capability and efficiency over the last 25 years; thus, monitoring and ensuring compliance of IMS stations with the technical and operational requirements specified in the relevant draft operational manuals is of paramount importance for the effectiveness and efficiency of the IMS network. In this context, (near) real time monitoring and early detection of potential failures of IMS stations (discussed in P4.1-722 and P4.1-079) are important enablers for effective control and evaluation. Complimentarily, the inclusion of probability statistics and the number of failures of stations over time are important data to be considered as a means to assess IMS sustainability (which was highlighted during session T4.4 and side event SE-5-924). Overall, the continuous adaptation of the IMS is required to face future operational and technical challenges.



04.4-248: Concept of prognostic and health management for radionuclide systems.

Extract from Mechanical Systems and Signal Processing "Prognostics and health management design for rotary machinery systems—Reviews, methodology and applications" (Jay Lee, Fangji Wu, Wenyu Zhao, Masoud Ghaffari, Linxia Liao, David Sigeel, 2014)

During SnT2023, contributions on performance monitoring, maintenance activity and sustainment of systems included enhancements of data quality control tasks using interactive station monitoring tools in the IDC Operations Centre for fast and easy identification of data acquisition problems, as well as regular activities to ensure that station characteristics meet the requirements set forth in the draft IMS Operational Manuals (P4.1-670). Means of assurance of compliance with minimum requirements for stations that underwent major upgrades or equipment changes were also presented (P4.1-798).

Increasing IMS station data availability by minimizing downtime using notification systems to inform on the need to start to solve an issue was also highlighted. This increase provides results of a continuous analysis, which enables monitoring the performance of the stations in near real time, thus providing information on the status of detectors and offering feedback to the station operators.

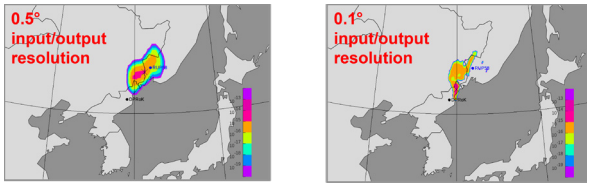
Focus was also given to tools for a global assessment of the IMS network performance and to assist the IDC in continuously monitoring and reporting on the operational status of IMS and IDC systems (P4.1-469). This included open source tools used in national networks that allow the detection of multiple problems in data transmission and provide basic data quality control including a notification system (P4.1-120); the use of parametric data from seismic bulletins to identify changes in IMS station performance and evaluate station quality (P4.1-240), and on the usability of state of health system to monitor in real time the status of the IMS (P4.1-314). The state of health of IMS stations, both from radionuclide and waveform technologies, is continuously monitored at the PTS to ensure the highest data availability. State of health programmes are undergoing improvements and upgrades (P4.4-759) and new tools are under development to identify upcoming failures (O4.4-248). Research tools using artificial intelligence, machine learning (P4.1-249) and an automatic data quality analysis system based on fuzzy logic (O4.1-479), were also presented to assess the station installation or station failure, to quickly diagnose equipment problems, and to provide input and trigger the required engineering or maintenance activities (P4.1-598).

6.2. Earth Characterization and Propagation of Signals

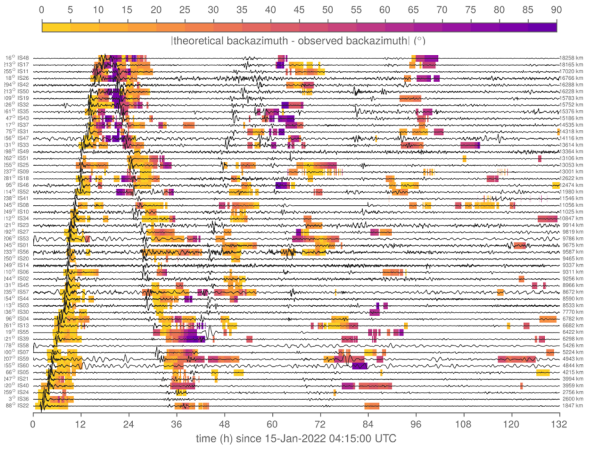
Understanding the earth's system poses a significant challenge for nuclear verification, for garnering support for the CTBT and for facilitating scientific applications in the civil domain.

6.2.1 Atmosphere (Radionuclide Monitoring)

Local scale experiments employing an array of instruments, including scanning LIDAR demonstrate that an accurate grasp of the influence of near field air flow on the long range transport of radionuclides in the atmosphere after an underground nuclear explosion necessitates refined modelling at that smaller scale. The data output from these instruments can be utilized to enhance high resolution meteorological models (O1.1-849). The atmospheric modelling community is still in the process of determining the best practices for configuring multiscale models to effectively address the complex interplay between mesoscale meteorological



P1.1-506: Global ATM simulation with ECMWF input data for the announced DPRK nuclear test in September 2017. Simulations run forward with a release from the test site and a snapshot was taken for the same time for a low resolution with 0.5° (left panel) and a high-resolution with 0.1° input and output resolution (right panel). The snapshots demonstrate the effect a complex area may have on the transport pathway and reflecting local meteorological effects. In the left panel, we witness the potential detection at IMS station RUP58. The right panel shows a more nuanced non-detection.



O1.4-514: Global instrument corrected infrasound recordings sorted by distance from the source, with one sensor trace displayed per IMS station (pressure channels bandpass-filtered between 200 and 5000 s). The colouring displays back azimuth deviation from PMCC low frequency detections. The clear "M" shape on the waveforms denotes Lamb waves propagation. The "M" shape is progressively deformed after one global circulation as infrasound waves travel slower than Lamb waves and are very sensitive to the atmosphere dynamics.

Vergoz J. et al. , 2022. IMS observations of infrasound and acoustic-gravity waves produced by the January 2022 volcanic eruption of Hunga, Tonga: a global analysis, Earth planet. Sci. Lett., 591, doi:10.1016/j.epsl.2022.117639.10.1016/j.epsl.2022.117639.

phenomena like frontal passages and microscale meteorology in the vicinity source emissions. This challenge arises from the essential requirement for a comprehensive and diverse set of observations that should accompany modelling studies. The analysis of multiscale simulations of transport and dispersion conducted during campaigns show significant steps taken in the journey toward establishing optimal methodologies for future multiscale modelling endeavours (P1.1-180). The current ATM operational system being operated for supporting the verification technologies at the PTS is based on a globally developed open-source Lagrangian particle dispersion model called FLEXPART. A PTS specifically curated version is integrated in the ATM pipeline of the IDC and provides real time products. The latest version of the software has a more modular way of organizing the source code and includes more flexible parallelization solutions and a reduction of absolute transport conservation errors (P1.1-577). The latter is not only promising for exploring high resolution ATM capacity in the IDC when it comes to including complex terrain and its dense mesoscale meteorology within the atmospheric boundary layer (P1.1-506), but also for exploring the minimal operational requirements for ensemble prediction computations required to support uncertainty quantification studies.

Addressing challenges related to scale and harvesting the benefits of considering the meteorological uncertainty of a chaotic atmosphere can be achieved through the utilization of ensemble numerical weather prediction systems in operational dispersion modelling. This involves incorporating emission and observational data from sources such as medical isotope production facilities, nuclear power plants and reactors, and the IMS, respectively. Coupling ensemble numerical weather predictions with ATMs is widely studied but to date few centres produce ensemble ATM output on an operational basis (i.e. on demand in response to incidents) using radioxenon stack monitoring data (P1.1-588).

6.2.2 Subsurface Radiotracer Processes

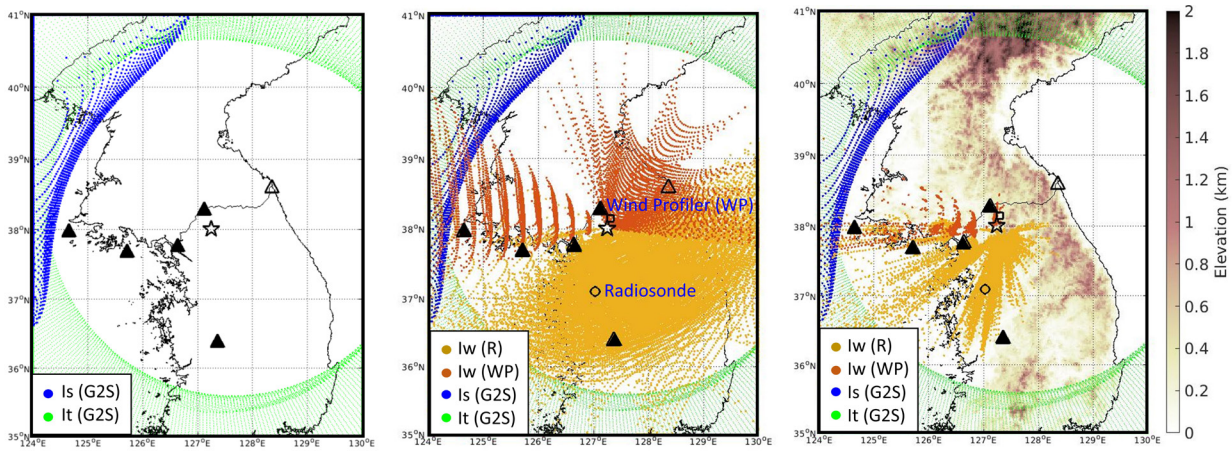
The emission of noble gases resulting from subterranean nuclear explosions was examined (O2.1-118, P2.1-678 and P2.4-271) using sophisticated models that accurately represent the physics of cavity formation during a nuclear detonation and subsequent migration to the surface. These models encompassed the cavity partitioning process, immediate gas venting caused by drill-back, pre-existing conduits, or fractures, as well as the later seepage driven by barometric forces. The implications of these models on event analysis and screening methods are further discussed in Section 6.4.

6.2.3 Atmosphere (Infrasound Technology)

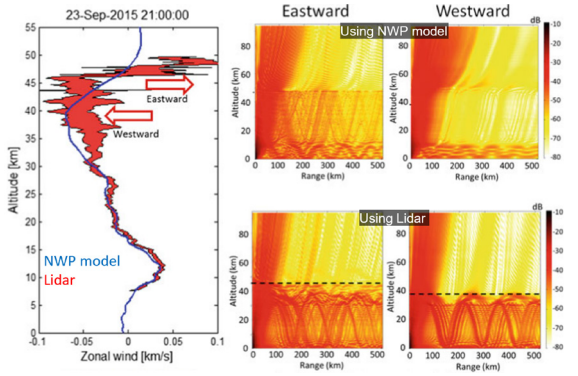
Long term changes in atmospheric temperature, revealed by analysing fifteen years of seismoacoustic data (O1.1-077), directly support the study of climate change. Unravelling temperature variability, both long term increases and decreases, from the surface based recordings remains challenging. Using both seismic and infrasonic signals, changes in the recordings can be attributed to changes in the medium; the latter being temperature changes in the troposphere and stratosphere.

Weather models have proven capable of predicting noise levels at infrasound stations, arising from turbulent processes in the lowermost atmospheric region (O1.1-805). Also relevant in this context, other studies focused on rainfall patterns in tropical areas, geomagnetic storms in Latin America and other natural phenomena that may be linked to seasonal fluctuations of detections in bulletins of IMS infrasound stations.

Noise is a significant hinderance for all waveform technologies, particularly in the context of infrasound technology where noise strongly affects the detection capability of stations. The study of noise generated by local atmospheric turbulence or of nuisance sources remains of high interest to the infrasound community leading to a wide range of applications on source discrimination, calibration of the systems or long term analysis



*O2.3-340: Ray tracing using **left** only the ground-to-space (G2S) atmospheric specification at the source (star) for the event time and date, and G2S and local weather data (radiosonde and wind profiler); **middle** without topography and **right** with topography. Phase identification (Iw: tropospheric, Is: stratospheric and It: thermospheric phases) is based on the turning height of the ray. Solid and open triangles represent infrasound arrays with and without detection.*



Pa2.4: Lidar observations provide insights into the actual state of the waveguides with higher accuracy than numerical weather prediction models like ECMWF. The shown example was measured by Lacy/LATMOS at the Maïdo Observatory, La Réunion. (Presented by Constantino Listowski at Panel 2.4).

Blanc, E. et al. (2019). Middle Atmosphere Variability and Model Uncertainties as Investigated in the Framework of the ARISE Project. In: Le Pichon, A., Blanc, E., Hauchecorne, A. (eds) Infrasound Monitoring for Atmospheric Studies. Springer, Cham. https://doi.org/10.1007/978-3-319-75140-5_28 Reproduced with permission from Springer Nature

of seasonal trends. In P1.1-675 the impact of atmospheric gravity waves and their energy on the propagation path of infrasonic waves and their transmission loss was studied. Small scale perturbations of gravity waves can help explain the presence of infrasonic waves in the acoustic shadow zone, which are not explained by operational atmospheric models (P1.1-541). Infrasound propagation is driven by middle atmosphere dynamics, predominantly winds and temperature changes, however, their dynamics are not well resolved by current numerical weather prediction models. Panel Pa2.4 demonstrated how LIDAR observations can provide amplitudes and periods of waves in the middle atmospheric layers. Furthermore, propagation path effects of infrasonic waves can be explained by utilizing accurate atmospheric and local weather data and high resolution topography. Such parameters can be used as input for propagation modelling techniques (O2.3-340 and P1.1-808), which in return will lead to improved location and characterization of infrasound and seismoacoustic sources.

Other sources of infrasonic noise are wind turbines (P1.4-112 and P1.4-587) and cyclones which form a source of coherent noise (P1.1-672). While such nuisance sources can perturb the mission of the CTBTO as it impacts station detection capability on local to regional ranges, which then affect the overall performance of the network, studies of those sources can lead to a better understanding of the infrasound noise field and help to better characterize the propagation medium and atmospheric specifications, and assist in the decision process for site selection of infrasound station installations being planned.

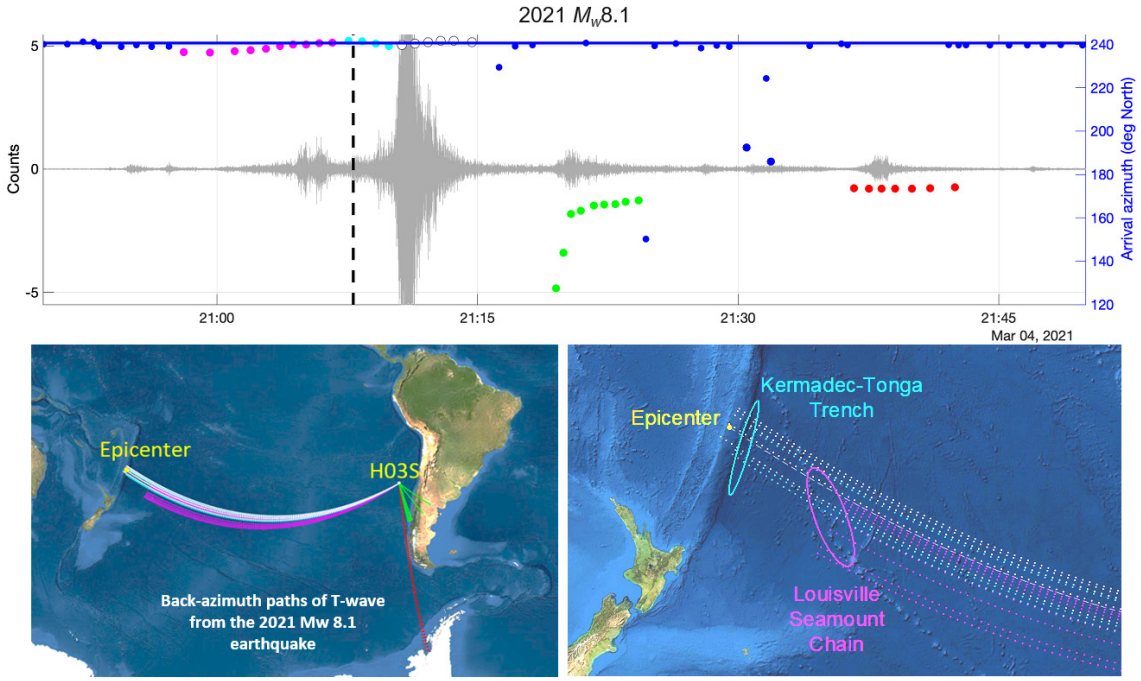
6.2.4 Seismic Technology

Several local and regional velocity models in areas with high travel time uncertainty were presented (P1.2-213, P1.2-433 and P1.2-446), which can improve event location accuracy

and precision. Two presentations assessed the performance of the RSTT velocity model, a global velocity model for regional phases, in Mongolia (O1.2-084) and Venezuela (P1.2-437). The RSTT is currently being used in the IDC for the calculation of travel times of regional phases and is considered as a 2.5-D velocity model as it considers distance and depth but also accounts for lateral heterogeneities. The accuracy of travel time predictions can be significantly improved using 3-D velocity models, however, ray tracing using 3-D models is too slow for operational systems. Machine Learning for Travel Time emulation (O1.2-179) is a deep learning method for emulating seismic phase travel times based on a 3-D earth model that meets the operational speed requirements. A limitation with using velocity models which have been generated using different inversion techniques is that their comparison is not consistent. This issue can be addressed by using a consistent travel time framework as presented in P1.2-139. Aftershock processing was studied with the objective to automatically detect phases and build earthquake catalogues, and results from deep learning methods were introduced (P3.5-348 and P3.5-780).

6.2.5 Hydroacoustic Technology

Hydroacoustic blockage is a severe limitation to hydroacoustic processing at the IDC. In P1.4-584 it was shown that T waves can be recorded at IMS infrasound stations and seismic stations (3-C and arrays) and concluded that seismic and infrasonic stations can be used to detect hydroacoustic signals and complement the IMS network in case of hydroacoustic blockage and that T phase stations can potentially be used to identify the back azimuth of hydroacoustic signals. Hydroacoustic blockage can also be dealt with by modelling 3-D underwater propagation effects, such as refraction and diffraction as was shown in P1.3-858 in a variety of scenarios such as interaction with seamounts, islands, ridges and coastlines. 3-D propagation modelling requires significant memory storage and computation power capabilities. To overcome this a marching scheme using Green's theorem was employed to develop a 3-D propagation model in a homogenous layer (P1.3-534).



O1.3-307: 4 March 2021 earthquake (Mw 8.1) and T phases generated by various coupling mechanisms. ***Top*** *waveform recorded at the IMS hydrophone triplet H3S. The dots represent the direction of arrival of detections at different times; T waves coupling occurred at Louisville Ridge (purple), the Kermadec-Tonga trench (cyan); green dots denote waves reflected off the coast of Chile and red dots possibly reflections from Antarctica.* ***Bottom left*** *propagation paths.* ***Bottom right*** *detail of bottom left panel close to the epicentre.*

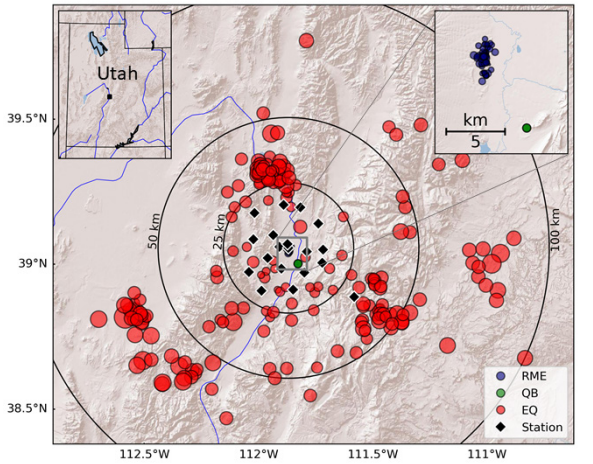
Oliveira et al., Megameter propagation and correlation of T-waves from Kermadec Trench and Islands. Frontiers in Marine Science, 9, 1009013, (2022).

In O1.3-307 recordings of eight large earthquakes close to the Kermadec trench recorded at HA3 are analysed and it is shown that the H phases recorded were in fact T waves coupled to the sound fixing and ranging channel near the epicentre, at the Kermadec trench or farther away at the Louisville Ridge seamount chain. The understanding of T wave coupling mechanisms can significantly improve interactive analysis and review (O1.3-579).

Studies on hydroacoustic noise were also a focus of importance. In particular, ship noise was modelled in P1.3-299 using the RAM parabolic equation solver, the Ambient Noise Directionality Estimation System model, interpolated bathymetry from the Smith and Sandwell global topography model. T and S phase fields from the Copernicus database and the bottom acoustic interaction near airgun shots was studied using 2-D and 3-D long range propagation models in (O1.3-536). High performance computing is an important topic for the hydroacoustic community outside and within the PTS, such computing capabilities are needed with increased performance prior to consideration for use at the IDC. A GPU implementation of RAM was introduced in P3.5-396, which achieves significantly faster simulations, while another presentation (P3.5-331) achieved a speed-up by a factor of 20 in 3-D broadband T wave propagation modelling using GPUs.

6.2.6 Seismocacoustic Source Characterization

Source characterization remains a challenging problem; criteria based on the ratio of P and S waves show limitations at local distances due to scattering and shallow earthquakes. Furthermore data from several past nuclear tests have led to the computation of the Ms:mb criteria with values close to those of earthquakes. Moment tensor and source-type analyses may help in discriminating between collapse events and explosions, although usage of such techniques is currently a challenge for the IDC (O2.3-448). Rapid moment tensor inversion has also been used to quickly characterize sources as nuclear explosions or earthquakes (O2.1-290). In P2.3-490 it was shown that 3-D waveform modelling can greatly improve source characterization even in scenarios with poor azimuthal coverage. Another study (P1.2-586) uses the combination of different deep learning based methods and causal approaches for phase detection, phase association, event location and event discrimination, which were applied to different tectonic and instrumental contexts to discern between natural and anthropogenic seismicity (O3.5-197). Finally, an ambitious experiment, the Rock Valley Direct Comparison project has been designed so as to detonate two chemical explosions near the hypocentres of some anomalously shallow earthquakes on the Nevada National Security Site; the objective is to directly compare earthquake and explosion signatures originating from essentially identical hypocentres (O2.3-171 and P2.3-137).



O3.5-197: Redmond Salt Mine, 75 blasts (RME), 206 tectonic earthquakes (EQ) and 3 blasts from a mine/quarry (QB) were used to test and design effective discriminants for local distances.

Acknowledgments: This Low Yield Nuclear Monitoring (LYNM) research was funded by the National Nuclear Security Administration, Defense Nuclear Nonproliferation Research and Development (NNSA DNN R&D). Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525. The authors acknowledge important interdisciplinary collaboration with scientists and engineers from LANL, LLNL, MSTS, PNNL, and SNL. The views expressed in the article do not necessarily represent the views of the U.S. Department of Energy or the United States Government. SAND2023-13805O.

Efforts using machine learning and deep neural networks for seismoacoustic source characterization were highlighted at the conference. Two supervised learning models, support vector machines and random decision forests, were tested and evaluated (P3.5-327)

with the aim to classify infrasonic signals among storm related sounds, quarry blasts and other anthropogenic activity. In another study five artificial intelligence methods are trained on a 36-dimensional feature space to discern between an earthquake and a mining induced earthquake, between an earthquake and an explosion and between an explosion and a mining induced earthquake (P3.5-123). Lastly, eight machine learning techniques were compared with respect to their performance in discerning earthquakes from nuclear explosions (P3.5-524).

6.2.7 Hunga-Tonga-Hunga-Ha'apai Volcanic Eruption of January 2022

Several presentations, either e-posters, orals or invited talk, concerned themselves with the Hunga underwater volcanic eruption of January 2022, an event that was exceptional as far as the period, magnitude and duration of propagation of the atmospheric waves it generated, circling the globe multiple times. The Hunga eruption was also discussed by a panel of experts in Pa2.1 that reviewed the chronology of the volcanic activity and consequences of the eruption for the Tongan archipelago and beyond. The Hunga eruption did not generate only atmospheric waves but also seismic, hydroacoustic and recordings from all IMS waveform technologies, which are scrutinized by research groups (O1.4-085, O1.4-514 and I2.1-754). Meteo-tsunamis and tsunamis were generated by this eruption unprecedented on the IMS historical scale. All 53 IMS infrasound stations recorded atmospheric waves, either Lamb waves, acoustic gravity waves or infrasound waves. It also challenged current models of infrasound and audible range propagation and yield estimation of atmospheric sources. This event offers the opportunity to improve modelling capabilities for hydroacoustic and infrasound technologies. Given the strongly coupled domains it is an opportunity to better understand and characterize interfaces and multi-domain propagation methods.

Finally, the variety of technologies in addition to the standard IMS seismic, hydroacoustic and infrasonic stations used, prescribe applicable technologies for expert technical analysis of such events. In P1.4-821, long-duration, super-pressure balloons and geostationary satellite data were used to complement IMS infrasonic ground stations; in particular the super-pressure balloon measurements provided data with a very high signal to noise ratio as they were less affected by atmospheric turbulences compared to the level registered at ground based stations.

On the issue of wave propagation modelling and going beyond the Hunga eruption, a panel discussion (Pa2.2) debated the challenges in 3-D modelling of long range sound propagation in the ocean and the atmosphere. It also provided insights into the energy conversion at the interfaces and advances in seismic propagation modelling. The complexity of waveform signals at IMS stations was highlighted together with the impact of 3-D features along their long range propagation paths.

6.2.8 On-Site Inspection

The importance of exercising OSI equipment and procedures was addressed and the challenges of operating in environments such as the tropics was emphasized (O4.5-088). Several challenges were mentioned during the event including the issue of receiving data from positioning satellites due to tall and multilayered vegetation canopies. This would impact most inspection techniques, and methods or procedures to overcome this will need to be considered – particularly considering the upcoming IFE25 in Sri Lanka.

Remote sensing via satellite is a technique to identify a potential nuclear testing site by analysing surface disturbance. It is made possible by comparing current and historical optical satellite earth observation data of moderate resolution. A multivariate change detection algorithm, imagery animation, and other visualization techniques are utilized to analyse such data. For nuclear test explosions with a yield where such methods have limited

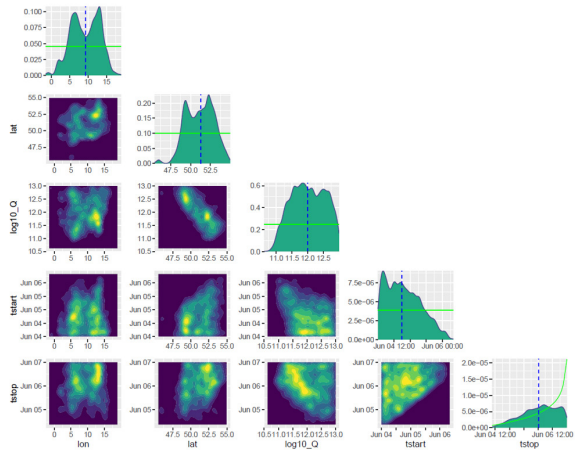
results, high spatial resolution optical imagery data might provide evidence of activities (traffic, digging, etc.) related to a nuclear testing event (P3.3-144). By employing both optical and radar remote sensing data from different space-based platforms, it becomes possible to better characterize the Democratic People's Republic of Korea tests by analysing displacement maps (and landslides) in 3-D (discussed in panel Pa2.4).

By utilizing improved photogrammetric techniques adapted for thermal infrared data, collected both before and after a conventional explosion experiment, it becomes feasible to process thermal images for signature detection. This innovative thermal photogrammetry method offers a novel approach to identifying anomalies and artifacts after explosions, measuring the extent of changes at the site and detailing the materials and distribution of fragmentation resulting from the explosions (O3.3-689). Preparations for an underground nuclear explosion are more likely to have significant magnetic anomalies than the explosion itself when activities are carried out at the surface. The preparation process and the device emplacement will require casing, cables, pipes, shafts, railways, etc. To obtain more insight into the qualitative and quantitative information obtained from magnetic measurements, both theoretical and practical models are required. Such measurements show the advantages and limitations of the different types of magnetometers. Comparing different magnetometers, based on different working principles in terms of the application and the survey results, are key in this respect (P3.3-257).

6.3. Processing of Data

As referred to in the previous section, the Hunga volcanic eruption in January 2022 presented a unique source of seismoacoustic signals to evaluate the performance of the seismic, hydroacoustic and infrasound networks of the IMS (referenced in Section 6.2.7). The nature of this event challenged the automatic processing procedures of the IDC and other scientific and operational establishments, which emphasized the need for new analysis methods that were developed and presented at the conference.

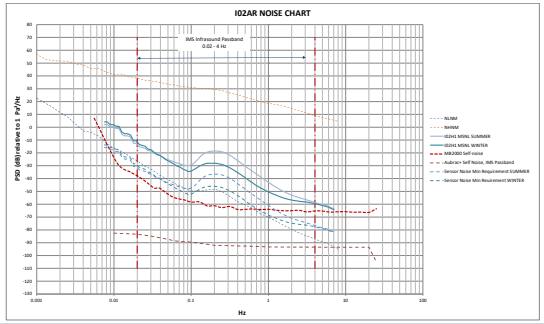
Analysis and understanding of noise are also essential to accurately detect and reconstruct sources that produce seismoacoustic waves. Detailed analysis of noise at infrasound stations provides information on the IMS minimum requirements for station specifications (P3.1-192). As an example of the connection between the scientific phenomena addressed by the PTS, seismic noise can arise from both hydrological (P1.3-516) and atmospheric sources (P3.1-558). Furthermore, the nature



P3.6-372: Source parameter probability distribution results from the FREAR software performing Bayesian inversion on a synthetic emission source

of noise signals across the IMS network can be leveraged to improve seismic travel time models (P3.5-408), to improve the estimation of event magnitudes (P3.5-277), to improve numerical weather prediction models and to assess optimum locations for installation of seismoacoustic installations (P1.1-805). The impacts of noise can be reduced using specialized algorithms such as the generalized F-detector (O3.5-285) and the Fischer scoring method (O3.5-485), which also assist in addressing challenges related to seismic arrays with varying characteristics and designs.

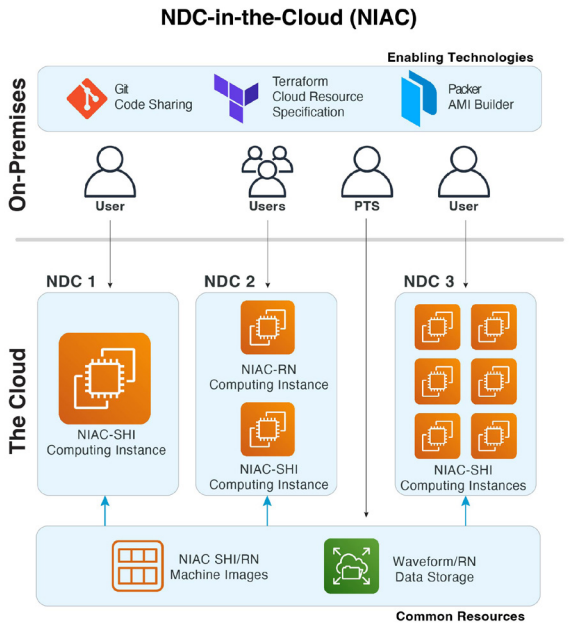
The PTS uses the nature of propagation of seismic, hydroacoustic and infrasound waves to form event locations while radionuclide



P3.1-192: Results of a noise study on infrasound element I02H1 on station I02AR. The power spectral density is measured as a function of frequency for winter and summer periods. The results are compared to the accepted low noise model (NLNM) and high noise model (NHNM) as well as required limits on sensor noise, self-noise of MB2000 microbarometer and equivalent digitizer self-noise.

results are recorded for each sample measurement. Radionuclide monitoring draws fresh inspiration from waveform processing techniques to automatically generate a comprehensive REB by synthesizing data from various measurements across the radionuclide network (P3.6-481). Efforts are also ongoing to define and identify events of radionuclide releases and their parameters including source location using Bayesian reconstruction techniques (O3.6-239, O3.6-460 and P3.6-372). Different samples that collect air masses from the same event can be associated with each other for example, by checking for decay consistency of activity ratios of relevant multiple isotope observations. With results from ATM like source receptor sensitivity, the source location of the release event common to the associated samples can be estimated (O3.6-364 and P3.6-412). Also the multi-model approach in defining the possible source region can enhance the source location accuracy (P2.4-334).

The isotopic ratio evolution is a key methodology to identify CTBT-relevant events and to characterize them regarding time, location and source type. The IDC has embarked on implementing an operational software environment to utilize methods for expert technical analysis to assist a requesting States in characterizing an event. This includes the use of activity ratios of CTBT-relevant radioxenons measured by the noble gas equipment at IMS radionuclide stations (P2.1-681 and P2.4-673). The identification of radioxenon emissions from nuclear explosions relies on the understanding of the contribution of established anthropogenic background sources, such as medical isotope production facilities, nuclear power plants and nuclear reactors. The noble gas products in the radionuclide pipeline of the IDC are still being completed; for example, according to I2.3-667, the "backtracking to known sources" flag requires further work on the information about the known sources (location, quantity and time pattern of the releases). Complementing this is research into prospective software implemented scientific solutions for the radioxenon background estimation and accompanying flagging in IDC products (P2.4-335). Further advancements refer to ATM studies of nuclear testing events and the resulting radioactive signature, which supports hypothesis testing and the accompanying classification and location of sources (P2.4-302).



P4.3-894: Block d iagram of the design of the NDC-in-the-cloud system.

For waveform technologies, machine learning methods are increasingly being investigated which can be applied to improve the data processing at the PTS. The NET-VISA automatic associator tool utilizes

Bayesian inference and has been developed for the IDC. For a number of years, it has been under testing and evaluation at the IDC as it is being considered for the IDC operational system (O3.5-424, P2.1-575, P3.5-461 and P3.5-892). This algorithm has been shown to perform better than the legacy software GA, especially for the characterization of lower magnitude events. Going further on event location, a study proposed to inject deliberate errors into event location prior distributions to calibrate origin location error (P3.5-891). Several presentations delve into deep learning and machine learning methods that can be applied to seismoacoustic signals to reduce noise and thereby increase the signal to noise ratio of real signals (P3.5-196, P3.5-176 and P2.1-222). Machine learning models that are trained on curated datasets can provide improved seismic travel times as mentioned in Section 6.2, improved phase detection (P3.5-449), improved estimation of back azimuth (P3.5-282) and enhance automated software in event localization and detection. Applied to IMS infrasound data and developed originally for waveform technologies, a deep learning approach is applied to the multi-channel maximum likelihood algorithm for multisource detection (P3.5-050), which offers an attractive perspective to enhance IDC capabilities. An additional use of machine learning is for anomaly detection, which can be used to identify anomalous radionuclide detections (O3.6-173).

The quality of the IDC products was presented at SnT2023. Studies of surface wave association have shown that some associations within the REB are not correct (P2.1-287). The contents of the REB have been compared against the results of the ISC to evaluate its relative performance over time (O3.5-256 and P3.5-656), which hints at improving the quality of the IDC products.

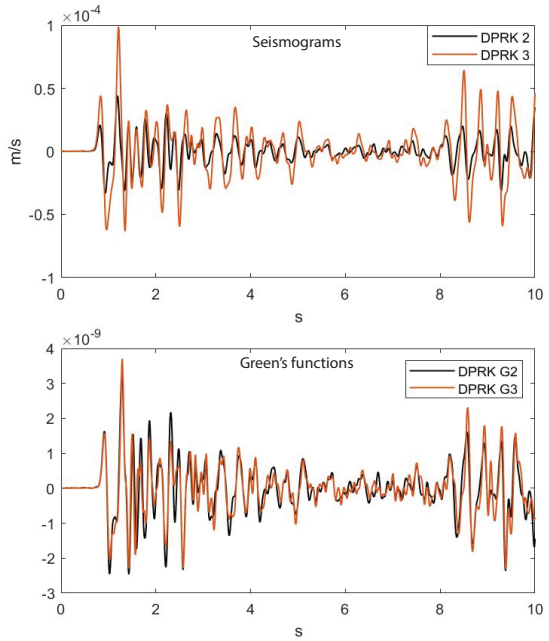
The use of remote and cloud-based systems improves the communication of information and reduces person power for maintenance. The NDC in a box software has been adapted to a cloud based service, which opens the possibility to further improve the distribution of IDC software to NDCs (P4.3-894) as it would enable stakeholders to carry out tasks not accessible on personal computers.

Remote calibration procedures for infrasound stations have been developed and are being deployed to an increasing number of stations (PTS-680). Such capabilities are being further refined and provide attractive avenues for the PTS for station certification and revalidation, but also for remote upgrade of IMS station software.

With the long standing objective to continuously monitor and assess the performance of the IMS, progress in signal and event detection capability remains an important topic for the PTS and several collaborating institutions. Studies assess the progress for event detection capability of the seismic network with a modern web-based system or define new metrics to evaluate the performance of the IMS waveform technologies (O4.1-582 and P4.1-469).

6.4. Historical Data and Events, Event Physics and Screening Methods

Precise timing of the Trinity nuclear test was presented in O2.5-518. The timing of the origin of this event is challenging, as the radio timing services failed. The author resorted to an earlier conventional explosive test (7 May 1945) conducted in a nearby location, and from cross-correlation analysis of scanned and digitized seismogram recordings of the nuclear test, compared with the recordings of the earlier conventional test, was able to time the Trinity test on 16 July 1945 at 11:29:24.5 UTC with a few tens of seconds tolerance. P2.5-186 presented the results of digitization of seismic bulletins of analogue stations between 1951 and 1992 from the national bulletins of Kazakhstan, Kyrgyzstan and Tajikistan. The metadata of all seismic stations of that period were also collected. The national network bulletin data were then combined with the ISC bulletin to form the comprehensive bulletin for Central Asia between 1951 and 2017. The results show



O2.1-326: The figure shows that given the proximity of the test locations, Green's functions from these events to the seismometer turned out to be nearly identical, and source functions were calculated.

significant improvements regarding seismicity and allow for a more accurate determination of active seismic zone boundaries. Historical geophysical data from the peak times of nuclear testing is generally difficult to obtain. Contribution O2.5-138 presented previously unreleased data from the Livermore National Network between 1979 and 1992, containing over 100 recorded nuclear tests as well as over 50 collapses associated with a nuclear test, and discussed challenges in preserving and correcting waveforms from historical recordings.

There is an urgent need to undertake similar efforts of recovering legacy data of historic nuclear tests from infrasound, hydroacoustic and radionuclide sensors. One presentation dealt with atmospheric radionuclides released by historic nuclear test explosions and observed at a large distance. P2.5-320 presented the observation frequency of different fission and activation products.

Source parameters and time functions for the five Democratic People's Republic of Korea nuclear tests from 2009 to 2017 were derived by Bayesian inversion of seismic records of the Mudanjiang seismic station in China and presented in O2.1-326. Given the proximity of the test locations, Green's functions of the seismograms from these events were confirmed to be nearly identical to each other, and source time functions were estimated. With source functions available, the Green's function from the Democratic People's Republic of Korea test site to any other seismometer can now be obtained by deconvolving the recording from the respective source function for the event, allowing an accurate characterization of the propagation path. Characterization of non-explosive events which can increase the false alarm rate is also an area of research that can improve CTBT monitoring. O2.1-164 examined collapse events from around the world associated with mining or nuclear testing, showing progress toward the development of a collapse source model as complementary to the earthquake and explosion source models. A tool for rapid seismic source characterization by moment tensor inversion, which enables rapid screening of nuclear test events but has also applications to earthquake monitoring and tsunami warning was presented in O2.1-290.

Infrasound observations of a rare earth grazing fireball were studied in O1.4-540, characterization of such unusual and long lasting sources at high altitude are useful for advancing monitoring goals for event identification and characterization. More generally, acoustic characterization of infrasound sources such as fireball events (P1.4-482) or paroxysmal volcanic eruptions (P1.4-472 and P1.4-796 and discussed in Section 6.2.7) may have useful applications in terms of screening of infrasound events for nuclear explosion monitoring. In this context, it is noted that the Hunga eruption of 2022 provides a unique dataset for the study of propagation of infrasonic waves over global distances, which allow the further evaluation of the source characterization methods traditionally in use.

A radionuclide source term modelling package for rapid scenario determinations with atmospheric transport models, which accounts

for test configuration and subsurface gas transport, based on empirical laws, tabulated data and computations, was presented in O2.1-118. A similar end to end numerical simulation of explosion cavity creation, cavity circulation processes, subsurface gas transport and prompt atmospheric releases is reported in P2.4-271. Radioxenon isotopic composition of release scenarios based on realistic models of underground nuclear explosion cavity evolution and subsurface gas transport were presented in P2.1-678. By adjusting various parameters, it is possible to replicate the radioxenon composition released from both the cavity and the surrounding rock. This ability to model different parameter sets has significant applications in distinguishing between events and estimating the time of detonation. A novel rock evaluation for geological modelling is using electrical conductivity and P wave velocity measurements to generate 3-D maps of the testbed porosity, permeability and water saturation to serve as the framework for transport modelling at the site (P2.4-817). With simplified assumptions, the detectability of prompt and delayed venting with different degrees of fractionation is studied based on simulated fission products from an underground nuclear explosion (P2.4-361). It is important to know what kind of radioxenon concentrations and ratios can be expected due to natural processes in the ground in order to be able to discriminate them from the signature of a nuclear explosion during a CTBT OSI. For this purpose, a series of measurements was performed in Sweden (P2.4-637). For OSI, besides radioxenon, also the understanding of argon-37 concentrations are important and these were studied with samples collected in field campaigns (O2.4-846).

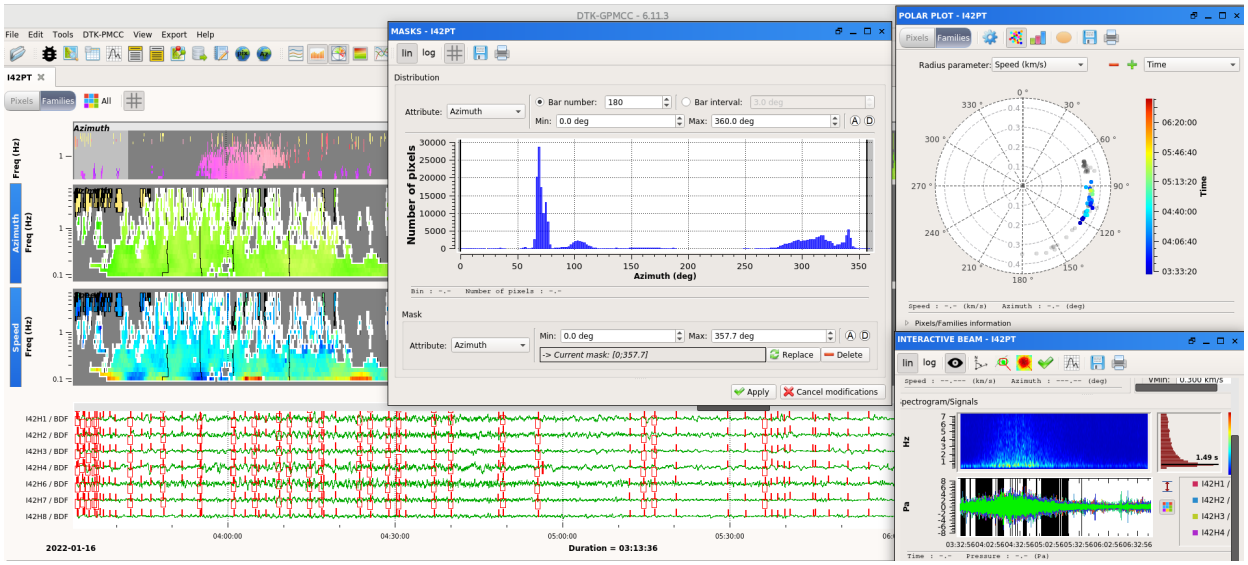
Data collected by the STAX project (P2.4-243, P2.4-341 and P2.4-367) prove to be instrumental for better understanding radioxenon sources and their impact on IMS noble gas systems, including medical isotope production facilities (P2.4-232 and P2.4-818) and a nuclear power plant (P2.4-370 and P2.4-049). Molten salt reactors are currently under development and testing in various countries with the first planned to go into operation in 2025 (P2.4-592). These reactor types are predicted to have radioxenon and radioiodine signatures that are indistinguishable from a nuclear explosion (O2.4-393). Typical radioxenon to radioiodine ratios of releases from nuclear power plants were established and compared with the signatures that may indicate a nuclear explosion in P2.1-323 . The results may be used for screening of samples at co-located particulate and noble gas systems P2.1-324. Automatic procedures for selecting samples associated with a release event based on the evolution consistency of isotopic ratios were presented in P2.1-521. The radioxenon isotopic ratio screening flags may be enhanced with thresholds that are adjusted to optimize the screening power (O3.6-769). Possible alternative statistical approaches were suggested to assess the radioxenon "anomalous values" against atmospheric background and to support a proper definition of anomalous activity concentrations (P3.6-718).

6.5. CTBT in the Broader Context

This section addresses the broader context of the CTBTO at the international level, namely, the use and sharing of IMS Data and IDC products for disaster risk reduction and scientific applications, sharing knowledge for capacity building and empowerment as well as global policy making, international collaboration and public awareness.

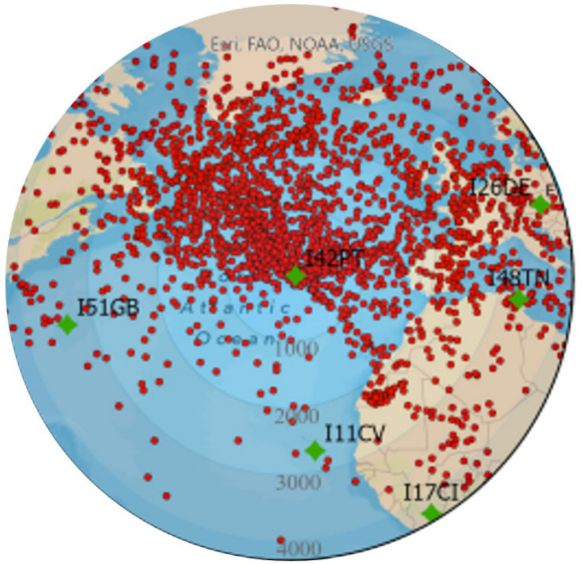
The buildup of the verification regime of the CTBTO has been progressing steadily over the last 25 years. In numbers, the installation of the IMS has surpassed 90%, IDC commissioning is in an advanced stage of Phase 5 and the OSI Division is currently conducting the third training cycle for surrogate inspectors in preparation for IFE25.

The IMS has proven its mission capability in nuclear explosion detection, as all the six announced nuclear tests conducted by the Democratic People's Republic of Korea were detected. In addition to the main verification objective, the system continuously records data associated with a wide range of non-



2011 - 2020

Year	I42 detections	SEL3 events	REB events
2011	349 079	158	36
2012	185 968	133	16
2013	211 617	154	10
2014	137 544	146	8
2015	100 467	110	4
2016	179 455	210	13
2017	172 677	434	22
2018	23 115	552	20
2019	146 422	500	16
2020	198 650	398	18
total_events	1 704 994	2795	163



P3.5-721: 2011-2020: A Decade of Observations at IS42, Azores, Portugal.

nuclear explosion related events, such as earthquakes, explosions, radionuclide releases, etc. Overall, the IDC recorded close to one million seismoacoustic events in its bulletins and categorized more than half a million radionuclide spectra across the world (P3.4-573). These data and products are available for civil and scientific applications through vDEC or they are directly shared with 20 tsunami warning centres in 19 States.

6.5.1 Civil and Scientific Applications

The use of IMS and non-IMS data for non-verification purposes was discussed already on the opening day of the conference, on multiple occasions during the High Level Opening and in panel discussions (Pa2.10, Pa2.11 and Pa2.12). This included the utilization of IMS data in synergy with data from national networks, multidisciplinary studies and the benefits gained from observatories responsible for tsunami warning and prospects for other future uses for disaster risk reduction, often referred to as civil applications. The tsunami warning framework was heavily covered in the T5.2 session, volcanic ash risk mapping (P5.2-611), radiation spreading from nuclear accidents (P5.2-321) and global warming were some of the topics included in the session dedicated to synergies with global challenges. The progress of the ARISTOTLE-eENHSP project, which involves twenty-four national and international organizations in

15 European countries delivering real time multi-hazard expert advice on worldwide natural disasters to the European Emergency Response Coordination Centre was introduced in an invited presentation I4.3-895. Experts discussed global seismoacoustic observations associated with large earthquakes (the 2023 south east Türkiye doublet with I4.2-897), explosions (P1.4-792) and volcano eruptions (see Section 6.2.7 on the Hunga eruption of 2022 and in panel discussion Pa2.1).

The virtual Data Exploitation Centre provides access to IMS data for scientific studies (P5.2-288). Since 2011, vDEC contracts have been concluded with institutions representing 29 countries and three international organizations. A variety of scientific methodologies were presented using IMS data and other data (standalone or in combination) for scientific applications such as infrasound emissions generated by large wind turbines (covered in e-posters in T1.4) and end to end numerical simulations of the impact of bolides (fireball and cloud generation on earth or oceans) using high performance computing (P1.4-272). The close relationship between atmospheric transport and infrasound measurements provided an overview of applications devoted to the study of climate (covered in several talks in T1.1 and T5.2) and accidental non-nuclear explosions (O1.1-024 and P1.4-795).

6.5.2 Sharing Data and Knowledge for Capacity Building and Empowerment

The empowerment to emerging NDCs with the CTBTO capacity building programme - not only for Treaty verification but also for national needs - was addressed and presented in T5.3: Africa (one oral and seven e-posters), Latin America and the Caribbean (three orals and seven e-posters), Middle East and South Asia (3 e-posters) and South East Asia, the Pacific and the Far East (2 e-posters).

The aspect of data sharing and knowledge transfer among technical experts is one of the most important issues for engaging research centres, national and international institutions with the CTBTO. Accordingly, it was one of the objectives of SnT2023 and several programme elements focused on this topic. A panel on enabling regional capacities and NDCs discussed the synergy between the CTBTO and regional experts and how national institutions have benefited from the possibility of using data from their regions, and all over the world, to improve their capabilities and to establish regional cooperation (Pa2.6). Another panel in the French language elaborated on the challenges in operating networks and the benefits of using vDEC IMS data in combination with local data with the advantage of engaging with other NDCs in a common language during capacity building training (Pa2.10). The P3.4 e-poster session illustrated the use of NDC in a box for integration of IMS and local data (P3.4-407), the synergy of CTBTO technologies and national technical means (P3.4-513), including a snapshot of the IDC as it stands in 2023. An example of knowledge sharing and learning from peers is the use of inverse ATM applied to an NDC Preparedness Exercise (O2.4-549). Another illustration of this concept was created by the uniqueness of the Hunga eruption of 15 January 2022, where several dozens of researchers from multiple institutions worldwide decided to collaborate to produce the most comprehensive study as possible of the remarkable atmospheric waves generated by the eruptions, which would have likely been beyond the capabilities of a single research group (as discussed in Section 6.2.7).

6.5.3 Policy and Advocacy

The conference panels and sessions under the umbrella of "Policy and Advocacy" illuminated the critical role of international cooperation and advocacy in advancing the CTBT and its overarching objectives. The summary presented in this section, delves into the key highlights and insights from the discussions and presentations, showcasing the multifaceted efforts of diplomats, experts and professionals in promoting the Treaty and enhancing its verification capabilities.

I4.4-901 provided numerous examples of transparency related to activities at sites of NNSA. Significant information is shared about plans and operations at the Nevada National Security Site and about the stockpile stewardship activities such as subcritical experiments.

In a panel devoted to European Union–CTBTO cooperation (Pa1.1), the extensive support that the European Union has offered to the CTBT and its verification mechanisms was discussed. The cooperation supports programmes for maintenance and upgrading of seismic stations, software development to enable in-depth analysis of data related to seismoacoustic events, greatly enhancing NDC capabilities. It also assisted in the regional introductory courses in Thailand and Slovakia and the pilot project that aims to share knowledge on how countries could harness data from the IMS for civil and scientific applications, underlining the potential for peaceful uses of CTBTO data. The panellists stressed the necessity of capacity building among various stakeholders, including youth, parliamentarians, journalists and scientists.

Aspects of multilingualism and its importance to international discussions as a means to better balance the exchange of ideas and international relations was addressed at the French speaking panel on the contribution of the Francophonie to international discussions (Pa1.2). There was agreement that the use of monolingualism poses a real challenge in terms of accuracy, rigour of thought, nuances and effectiveness of debates and understanding for many delegations that do not speak in their mother tongue. It encouraged the CTBTO to expand the use of other official languages in its documents, harnessing recent technological innovations to provide efficient and cost effective translation services.

SnT2023 built on the tradition of SnT conferences of supporting the participation of young experts. This time, they were not only audience participants with youth dedicated side events, but much more than before they were integrated as SPC members, speakers, presenters, panellists and moderators. In a panel discussion on Next Generation (Pa2.7), Ambassador Abel Ayoko underscored the unique value of including youth groups in discussions, as they bring fresh perspectives, innovative concepts and distinct problem solving approaches. The panellists shared their experiences collected during their journeys as members of CYG and YPN. They noted that the long term impact of CYG extends to building a network of members involved in policy dialogues in Annex 2 States. Meanwhile, YPN seeks to establish a pool of highly competent technical experts dedicated to supporting the mission of the CTBT, while promoting diversity and gender balance. Panellists encouraged CYG to foster connections with youth groups known for their policy impact but also advocated for more interdisciplinary cooperation and engagement with initiatives related to SDGs and climate change.

A joint panel discussion between the CTBTO and UNODA delved into the pivotal role of technological advances in strengthening multilateral verification regimes (Pa2.9). The discussion emphasized the significance of science and technology in enhancing the effectiveness of verification across various multilateral verification regimes for preventing the proliferation of weapons of mass destruction. Furthermore, the panel explored mechanisms for monitoring technological advances and facilitating knowledge transfer among stakeholders. Collaboration and knowledge sharing among multilateral verification regimes were underscored as essential elements in

advancing global security. The panel concluded that science and technology developments are a common denominator for achieving advances and maintaining confidence in the system. Best practices and successful procedures of one regime might inspire enhancements of another one. The SnT conference series sets an example for an open process of getting the community of experts together.

The intersection of science, technology and CTBTO-related activities was highlighted in panel Pa2.13. Speakers emphasized the robust connections between professional societies and encouraged active engagement with these communities to facilitate knowledge exchange, particularly from underrepresented regions. They viewed this collaborative engagement as a beneficial partnership which can create a valuable bridge between expert communities and policymakers. Speakers concluded by emphasizing the importance of providing training, scholarships and support to cultivate the next generation of leaders who will play an instrumental role in advancing global peace and security.

In conclusion, the CTBTO sessions under the theme of Policy and Advocacy provided a rich pool of insights and actions undertaken to advance the cause of the CTBT. From international cooperation to the invaluable contributions of youth and advancements in science and technology, these sessions have reinvigorated the dedication of the global community to achieving a world free of nuclear testing. Multilingualism and the collaborative spirit of the Francophonie further underscore the importance of inclusivity and dialogue in reaching this ambitious goal.

Appendix 1

Scientific Programme Committee

Appendix 1

Scientific Programme Committee

Atalay Ayele Wondem

Head of Seismology, Addis Ababa University, Ethiopia

Atalay Ayele Wondem is Professor of Geophysics (seismology) and is currently Head of Seismology at Addis Ababa University. He previously served as the director of the Institute of Geophysics Space Science and Astronomy at the university. He is currently involved in teaching and advising postgraduate students, coordinating and running the national seismic station network of the country, data analysis and research. He contributed to the success of several broadband seismic experiments in collaboration with overseas researchers. He was coordinator of the sub-Saharan Africa Global Earthquake Model and founding president of the African Seismological Commission. He is station operator and national point of contact for the Ethiopian NDC. He is Visiting Fellow of Leeds and Bristol Universities, United Kingdom (UK), and a fellow of the Ethiopian Science Academy. He is the recipient of the 2021 international award of the American Geophysical Union in recognition of making an outstanding contribution to furthering Earth and space sciences and using science for the benefit of society in developing nations.

Anna Berezina

Head of the NDC, Institute of Seismology of the National Academy of Sciences of the Kyrgyz Republic, Kyrgyzstan

Anna Berezina is the head of the NDC, Institute of Seismology of the National Academy of Sciences of the Kyrgyz Republic, the technical point of contact from Kyrgyzstan to the PTS, and the Kyrgyzstani expert at WGB. She has over 28 years of experience in seismic monitoring, seismic data processing and analysis, and has participated in many CTBT-related meetings, including SnT conferences, workshops and training courses since 1998. She has been a participant in different international projects, including the projects related to historical data digitizing and preservation, and seismic hazard assessment issues. She is the author of a number of publications related to seismic monitoring and historical data digitizing and preservation.

Silvia Blanc

Head of the Underwater Acoustic Propagation Department, Argentinian Navy Research Office and the National Council of Scientific and Technical Research/Ministry of Defence, Argentina

Silvia Blanc acquired her academic training in physics at the University of Buenos Aires and the International Centre for Theoretical Physics. Since 1974 she has worked on research and development in hydroacoustics at national institutions. Silvia Blanc's field of interest is modelling of underwater sound wave propagation, bottom interaction and acoustic scattering by volume elements. She has managed about 17 national and international research and development projects and has been a visiting researcher at the International Centre for Theoretical Physics; the Institute of Ocean Sciences, UK; the Atlantic Oceanographic and Meteorological Laboratory, Woods Hall Oceanographic Institution, Applied Physics Laboratory and the Naval Research Laboratory, USA. Her teaching activities cover undergraduate and graduate courses at the University of Buenos Aires and other national universities. She holds memberships in scientific associations related to marine sciences and is the Technological Advisor, in the Ministry of Science and Technology. From 2004 to 2012 she was President of the National Committee of the International Association for the Physical Sciences of the Oceans (IAPSO) and was a member of IAPSO Executive Committee from 2007 to 2015. She is the author of numerous scientific articles and technical reports.

Aristide Aly Boyarm

Founder and Chief Executive Officer of Africa CRM&SI, IT Strategy Consultant, Burkina Faso and France

Aristide Aly Boyarm is the head of Africa CRM&SI, a firm based in Ouagadougou, Burkina Faso, that assists companies in their search for IT performance. He is the founder of the online platform devchampion.net that detects and hires talented African developers for companies and startups after going through a rigorous selection process and online tests. Previously, he worked for leading European companies specializing in IT services and solutions, managing information systems evolution projects. He is a lecturer in computer science at the Nazi Boni University in Bobo, Burkina Faso, and holds a PhD in Computer Science from the University of Aix Marseille, France, and an MBA from the Sorbonne Business School, France. He is the author of the book *The African Digital Enterprise*, CEPRODIF edition 2018.

Peter G. Brown

Professor in the Faculty of Science, Department of Physics and Astronomy, University of Western Ontario, Canada

Peter Brown's research interest focuses on small bodies in the solar system, including the origin and evolution of meteoroids, radar, optical and infrasonic measurements of meteors, meteorite source regions and large bodies interacting with the Earth's atmosphere and infrasonic and seismic detection of bolide airbursts. He was previously the director of the Centre for Planetary Science and Exploration and has been professor at the University of Western Ontario since 2008. During the course of his career, he has published several books, book chapters and 190 papers in refereed scientific journals, including covers in Nature and Science. He supervised numerous PhD students and was recognized in 2014 as Distinguished University Professor.

Mohamed Nabil Mohamed ElGabry

Associate Professor of Seismology at the National Research Institute of Astronomy and Geophysics, Egypt

Mr ElGabry is currently the Vice President of the African Seismological Commission and a member of the Egyptian National Committee for Geodesy and Geophysics. In addition, he is a non-resident expert for the Egyptian Permanent Mission to the CTBTO Preparatory Commission. His research primarily focuses on reducing the impact of natural disasters, with a special focus on protecting cultural heritage sites and improving seismological monitoring in Africa. Over the course of his career, he has been involved in coordinating and participating in various regional and international research projects and consultancies aimed at mitigating the impact of natural disasters.

Gustavo Haquin Gerade

Head, Radiation Safety Division, Nuclear Licensing and Safety Office, Israel Atomic Energy Commission, Israel

Gustavo Haquin Gerade holds a PhD in Hydrology in Soil Physics and a MSc in Nuclear Engineering. He is head of the Radiation Safety Division of the nuclear regulatory authority of Israel. He has been involved for almost two decades in radiation detection as head of the IMS radionuclide laboratory RL9 in Israel. He is a member of the Israeli delegation to WGB and an expert in the OSI verification regime and the draft OSI Operational Manual. He was a former head of the Policy Planning and Operations Section of the OSI Division. He is an expert in OSI techniques, mainly radionuclide, as well as OSI methodologies. He is a member of the scenario task force team for the development of the IFE25 scenario.

Daniela Veronica Ghica

Head, National Institute for Earth Physics, Romania

Daniela Veronica Ghica is the head of the Romanian NDC and the representative of

Romania to WGB. She obtained her PhD in Physics from Bucharest University, Romania, in 2011. Her area of expertise includes array seismology, test-ban monitoring and infrasound monitoring. Her competences in infrasound signal processing and analysis are materialized in the application of automatic and interactive techniques for detection and characterization of the natural/anthropogenic infrasound sources and seismoacoustic events. Her work includes the study of discrimination between explosions and tectonic earthquakes. She is involved in the development of the infrasound monitoring network installed on the territory of Romania.

Michelle Grobbelaar

Chief Scientist Council for Geoscience, South Africa

Michelle Grobbelaar has been involved with seismic monitoring in south and southern Africa since 1997. She has a vast knowledge in the installation of seismograph networks with the objective of monitoring ground vibrations within mining regions and around demolition ranges for various clients. With the data from these networks, she has led research to determine the effects of blasting on the communities surrounding mines. She has led research on microzonation and other seismic studies which have been instrumental to the country. Ms Grobbelaar regularly engages with the various key stakeholders within the mining fraternity in an effort to understand the effects of ground vibrations within the mining regions and she is currently focusing on the seismicity within the South African mining regions. She is a Task Leader at WGB for the Support to Provisional Operations as well as Technology Refreshment Tasks.

Ian Hoffman

Research Scientist, Radiation Protection Bureau, Health Canada, Canada

Ian Hoffman conducts research on CTBT and health protection topics that involve ionizing radiation in the environment. He has also played an active role in the design and operations of the Canadian NDC. Mr Hoffman has been a member of the Canadian delegation to WGB for more than 15 years and has served as the chair of the Joint Expert Group since 2013. The Joint Expert Group seeks to fuse monitoring data from multiple technologies into an integrated product to assist NDCs with their verification activities. Mr Hoffman has been a session chair and presenter at numerous CTBT events, including the International Noble Gas Experiment, NDC and Quality Management workshops, and SnT conferences. Mr Hoffman is also an adjunct professor at the Royal Military College of Canada.

Yoshiyuki Kaneda

Designated Professor, Executive Adviser to the President of Kagawa University, Vice Director of the Institute of Education, Research and Regional Cooperation for Crisis Management Shikoku, Kagawa University, Japan

Yoshiyuki Kaneda's specialty is seismology and disaster mitigation science. He led two large projects related to earthquakes and tsunamis in Japan. One of the projects dealt with developing an ocean floor network system in the Nankai Trough, through the Dense Ocean Floor Network System for Earthquakes and Tsunamis. The other project was concerned with seismic linkage around the Nankai Trough. He also conducted high performance computer simulations to predict the compound earthquake and tsunami hazards that were seen in the 2011 Tohoku disaster. He led an international earthquake research project with Türkiye from 2013 to 2018 (SATREPS). This project used simulations to visualize sea bottom observations and other research results and also aimed to contribute to earthquake and tsunami disaster mitigation in Türkiye. Mr Kaneda leads a SATREPS project again with Türkiye from 2023. He worked at Nagoya University until 2016 after working at the Japan Agency for Marine-Earth Science and Technology from 1997 to 2014.

LI Peng

Deputy Director General, China Arms Control and Disarmament Association, China

Li Peng has been the Deputy Secretary General of the China Arms Control and Disarmament Association since 2019. He is also consulting senior advisor to Hope Investment Development Co. He is a retired senior colonel working in the field of nuclear and conventional arms control, non-proliferation and export control at the Ministry of National Defense. Between 2011 and 2013, he worked in the OSI Division of the PTS. In 2011, he participated in the second training cycle of OSI training for surrogate inspectors. Between 2000 and 2011 he attended WGB meetings as a member of the Chinese delegation. Between 1997 and 2002, he engaged in the research of nuclear arms control and disarmament verification technologies, more specifically, CTBT verification technologies.

Anne Strømmen Lycke

Chief Executive Officer of NORSAR, Norway

Anne Strømmen Lycke has a Master of Science from the Norwegian University of Science and Technology and is a business graduate from the Norwegian Business School. She has over 30 years of experience in the oil and gas sector and has held high level positions in several large energy companies focusing on renewable energy, carbon capture and storage initiatives. In addition to being Chief Executive Officer of NORSAR, Anne Strømmen Lycke has a great deal of experience as chairperson and member of various boards such as tech startups, growth companies, renewable energy companies and utilities.

Alexey Malovichko

Scientific Leader, Geophysical Survey of the Russian Academy of Sciences, Russian Federation

From 2005-2018 Alexey Malovichko was the Director of the Geophysical Survey of the Russian Academy of Sciences – the organization responsible for earthquake monitoring of the whole territory of the Russian Federation, for the operation of tsunami warning systems in the far east of the Russian Federation and operation of the Russian segment of the IMS. Since 2003 he has been a corresponding member of the Russian Academy of Sciences. He has more than 30 years of experience in scientific activity connected with the monitoring of nature and mining induced seismicity, investigation of the structure of the Earth's interior, analysis of the fine structure of seismic noises, detailed study of microseismic wave fields above hydrocarbon reservoirs and pipelines.

Oladoyin Odubanjo

Executive Secretary of the Nigerian Academy of Science, Nigeria

Oladoyin Odubanjo is the Executive Secretary (Chief Executive Officer) of the Nigerian Academy of Science, which he joined about 15 years ago as part of a team to transform the Academy from a largely honorific to a service-providing organization. Mr Odubanjo is also the Chairman of the Africa chapter of the International Network for Government Science Advice. He serves on the boards of other organizations such as The Conversation Africa and The Leprosy Mission Nigeria. He has also served on national and international advisory committees especially linking evidence to policy making and implementation.

Paola García Peña

Station Manager of the Chilean IMS stations and NDC, Comisión Chilena de Energía Nuclear, Chile

Ms. Paola García Peña has been working at the Chilean Nuclear Energy Commission since 2014 and is in charge of all issues related to the CTBT in Chile. She studied management engineering among other fields related to the public sector in Chile. She has experience working as a station manager for stations HA3, IS13, IS14, RN18 and RN19 operating under post-certification activity contracts and she is in

charge of the Chilean NDC. She participates in WGB as a Co-Task Leader of Support to Provisional Operations and she is also part of the third cycle of OSI inspectors. She hopes to be able to contribute whatever is necessary for the Treaty to enter into force and for its data to be used in science.

Marino Protti Quesada

Director, Observatorio Vulcanológico y Sismológico de Costa Rica, Universidad Nacional, Costa Rica

Marino Protti Quesada obtained a PhD in Geophysics from the University of California in Santa Cruz in 1994 and a Master's Degree in International Relations and Diplomacy at the National University of Costa Rica in 2018. He studies subduction processes that generate large earthquakes and focused on the Nicoya segment of the Middle American Trench. He promoted and succeeded in having this subduction segment being chosen as an international laboratory for the study of seismogenesis. He helped build and operate a very dense geodynamic control network specifically designed to record the processes that led to the 2012 Nicoya earthquake. In 1994 he descended down to 4100 m in the Middle American Trench on board the submersible Alvin. In 1996 he was also part of a deep ocean drilling leg offshore of the Nicoya peninsula. The Arenal and Turrialba volcanoes have also been part of his research. In 2013 and 2016, he was part of expeditions to Antarctica, where he helped install geophysical instrumentation on the Willams Glacier. He has been Director of the Costa Rica Volcanological and Seismological Observatory, a Research Institute at the National University, for the periods 1985-1988, 1997-2002 and 2019-present. Twice, he was Director and Organizer of a Regional Course on Methodologies for Volcano Monitoring, sponsored by UNESCO. He organized more than ten international workshops and congresses both in Costa Rica and abroad. In 1996 he was awarded the Clodomiro Picado Twight National Prize in Science and in 2002 the National University awarded him the Roberto Brenes Mesén Prize for Academic Excellence. From 2004 to 2018 he was the Secretary of the National Academy of Science of Costa Rica. He was the President of the Latin American and Caribbean Seismological Commission of IASPEI from 2014 to 2016. In 2022 he was honoured with the Ambassador Award of the American Geophysical Union.

Paul Richards

Professor at Columbia University, USA

Paul Richards has taught at Columbia University in New York since 1971, where he has conducted research on the theory of seismic wave propagation, the physics of earthquakes and the interior structure of the Earth. He co-authored the advanced text *Quantitative Seismology* (available in English, Russian, Chinese and Japanese), and is co-discoverer of evidence for super-rotation of the Earth's inner core. He has been emeritus Professor since 2008 and received the Seismological Society of America's Reed medal for outstanding contributions to seismology. He participated for the USA in Geneva in the CTBT negotiations in the 1990s and worked with Ola Dahlman in 2006 to initiate what has become the SnT series of conferences sponsored by the CTBTO in Vienna.

Anders Ringbom

Research Director, Swedish Defence Research Agency, Sweden

Anders Ringbom holds a PhD in nuclear physics from Uppsala University. He has been employed at the Swedish Defence Research Agency, the Swedish NDC, since 1997and as part of his research there, he developed measurement systems and analysis methods for noble gas detection, including the radioxenon system SAUNA used in the IMS He is the Swedish representative to WGB.

Ricardo Sagarzazu

Senior Technology Advisor, INVAP S.E., Argentina

Mr. Sagarzazu is a physicist, with initial orientation in solid state physics. After a stay at MIT, he worked at Armed Forces Scientific and Technical Research Institute where he was one of the founders of the Microelectronics Laboratory, dedicated to the development and pilot plant of hybrid and integrated circuits, where he also directed the Semiconductor Process Technology Research and Development Laboratory. After joining INVAP he worked in different technological projects including radiation detectors for terrestrial and space use, as well as solid state, gaseous and multifilar detectors for high energy particle detection. Some of these developments were applied to the production of personal and effluent radiation monitoring equipment that INVAP supplied for nuclear installations in the country and abroad. After the space division was created at INVAP, he was in charge of the Villa Golf Facility, where the first three satellites of the SAC series and their payloads were integrated, tested and sent for launch. He is currently an advisor in the technology area at INVAP.

Dmitry A. Storchak

Director, International Seismological Centre, United Kingdom

Dmitry Storchak received a PhD from the Russian Academy of Sciences and is the author of several frequently referenced research publications. He worked at the International Seismological Centre, UK, as an analyst, senior seismologist, and the director, maintaining seismological data exchange with approximately 150 organizations in over 100 countries and producing the International Seismological Centre Bulletin and a number of widely used data products, such as the ISC-EHB, ISC-GEM, GT, Event Bibliography, and the CTBTO Link to the ISC database. He chaired the IASPEI's Commission on Seismological Observation and Interpretation that is responsible for setting standards in observational seismology such as the New Manual of Seismological Observatory Practice, the IASPEI Seismic Format, the IASPEI Standard Seismic Phase List and the IASPEI GT List. He is currently serving as the President of the European Seismological Commission.

Nortin Titus

Chief, Geophysicist, Ministry of Mines and Energy, Namibia

Nortin Titus is Chief Geophysicist at the Ministry of Mines and Energy in Namibia. He is the Head of Crustal Geophysics in the Geophysics Division. Crustal Geophysics is responsible for all CTBTO matters and seismology. Mr Nortin is an OSI inspector from the third training cycle and represents Namibia as a technical expert at WGB. He served as Chairman of the National Commission on Research, Science and Technology, was a board member of the Atomic Energy Board of Namibia and is currently nominated as Namibia's Commissioner for the African Commission on Nuclear Energy. His expertise is in geoscience, nuclear physics, nuclear non-proliferation and nuclear fuel cycle policy. He holds a BSc in Physics and Geology, a PhD in Theoretical Nuclear Physics from Stellenbosch University, South Africa, and is enrolled with the Department of Industrial Engineering at Stellenbosch University for a Master's in Engineering Management.

Magdalene Wangui Wanyaga

Project Manager, SandRose Ltd., Kenya

Magdalene Wanyaga is an early career geologist and geophysicist currently working as a project manager in the climate change, sustainable cities and environmental assessments fields, among others. She has been a CYG member since 2016 and is also a member of the CTBT Young Professionals Network. A scientist and strong believer in world peace, she seeks to enhance science communication to drive policymaking, especially in Africa and is keen on collaborations that promote

science diplomacy. She also advocates for nuclear non-proliferation and ratification of the CTBT while promoting awareness of the Treaty and the technologies used by the CTBTO, as well as the safe uses of nuclear energy.

Kathy Whaler

President, International Union of Geodesy and Geophysics, United Kingdom

Kathy Whaler studied for a BSc in Mathematical-Physics at the University of Sussex, UK. From there she moved to the University of Cambridge, UK, for a PhD and post-doctoral research in Geomagnetism, and was then appointed as a lecturer at the University of Leeds, UK. Since 1994, she has held the Chair of Geophysics at the University of Edinburgh, UK. Ms Whaler's research encompasses using magnetic observations from observatories and low orbiting satellites to investigate liquid iron flow in the Earth's core and the lithospheric magnetic fields of the Earth, Mars and the Moon; the development of geophysical inverse theory algorithms for geomagnetism and electromagnetic induction; and magnetotelluric investigations of the Earth's electrical resistivity structure, especially in the East African rift. Her honours include external membership of the Hungarian Academy of Sciences, Associate Fellowship of the Ethiopian Academy of Sciences, Fellowship of the American Geophysical Union and the Order of the British Empire.

YIM Man-Sung

Donald E. Bently and Agnes Muszynska Professor of Nuclear Engineering, Adjunct Professor, Graduate School of Science and Technology Policy, Director, Nuclear Nonproliferation Education and Research Center; Associate Vice President, International Office Korea Advanced Institute of Science and Technology, the Republic of Korea

Man-Sung Yim is a Bently Endowed Chair Professor in the Department of Nuclear and Quantum Engineering at the Korea Advanced Institute of Science and Technology where he has taught courses on nuclear risk management, nuclear energy policy, nuclear waste management, and radiation biology since 2011. He is Associate Editor (Asia) of *Nuclear Technology* for the American Nuclear Society, a member of the Editorial Advisory Board of *Progress in Nuclear Energy* and the *International Journal of Nuclear Security* and an editor of the *Journal for Peace and Nuclear Disarmament*. Mr Yim's work aims at safe and responsible use of nuclear technology. He authored a textbook on Nu*clear Waste Management: Science, Technology, and Policy*. He is a graduate of Seoul National University, the Republic of Korea, (Nuclear Engineering, BSc/MSc), University of Cincinnati, USA (Nuclear Engineering, PhD) and Harvard University, USA (Environmental Health Science, SM/ScD).

Appendix 2

Side Events (SE) and Workshop (WS)

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Side Events (SE) and Workshop (WS)

SE-1 Young Professionals Network

Reference: SE-1-922

The YPN held a side event during SnT2023 with the format of a panel discussion, including presentations on the future of the CTBT verification system and what are the opportunities for science and technology. The side event kicked off with a presentation on the CTBT and its verification regime. It was followed by a panel discussion of YPN members and mentors. The opportunities in science and technology to improve the operation and functioning of the verification system was discussed by the panellists with a view on the potential introduction of new technologies in the future. The panellists also contributed their views on challenges faced by the verification system in an ever-changing world with more frequent natural disasters. Perspectives from several NDCs were expressed during the side event.

SE-2 Working at the CTBTO

References: SE2.1-916, SE2.2-917 and SE-2.3.918

This side event had three occurrences during SnT2023, two of them being recruitment sessions, while the third one was a recruitment session specifically dedicated to young professionals. It was announced with the following text.

CTBTO is hiring professionals in STEM fields – Learn about CTBTO's Recruitment Process. Come and find out more about how to join the CTBTO! Visit us at the HR booth and speak with the CTBTO Human Resources team and learn more about CTBTO careers. You can also join us in our HR presentation where we will walk you through our recruitment process. CTBTO is hiring top talent across a wide variety of scientific and technical fields in seismic, radionuclide, hydroacoustic and infrasound technologies. There will also be a presentation focusing on students and young professionals interested in pursuing a career in these fields. We look forward to meeting you soon!

SE-3 SHI NDC in a Box User Group Meeting

Reference: SE-3-925

Based on the widespread usage of NDC in a box by NDC personnel, the IDC organized a user group meeting where representatives from development teams of key components of NDC in a box were present to answer questions. The discussions focused on the seismic, hydroacoustic and infrasound version of NDC in a box and it enabled discussion on recent developments and the future direction of the development of all major components, which are Geotool (developed by the IDC Division), SeisComP (developed by the GeoforschungsZentrum and gempa GmbH) and several *DTK* software components (developed by the Commissariat à l'énergie atomique et aux énergies alternatives)

SE-4 NPE - National Data Centre Preparedness Exercises

Reference: SE-4-923

A side event to discuss NPE took place during SnT2023, which allowed participants to discuss past and potential future exercises. The NPE is an independent performance assessment by multi-technological scenarios of potential CTBT violations. The exercise is organized by NDCs for NDCs.

The organizer introduced an overview of the NPE with a focus on the purpose of such exercises and their evolutions in the last 15 years. Scenarios from NPEs since 2007 were briefly presented and the latest NPE from 2019 was reviewed in length. This review elements led to a presentation on the status and plans for the upcoming exercises, tentatively called NPE 2023. It was followed by a discussion between the organizers and the audience.

SE-5 IMS Sustainment: Past, Present and Beyond

Reference: SE-5-924

At the SnT2023, the evolution and sustainment of the IMS was discussed by a panel chaired by the current IMS Director Xyoli Perez Campos and its former Directors Gerardo Suarez, Frederico Guendel and Seismic Section Chief, Sergio Barrientos.

The panellists examined the trajectory of the IMS from inception to its current state, and projected potential future directions. The panellists highlighted that initial opposition to the IMS was overcome and it successfully proved its capability and efficiency.

A key topic discussed was the significance of IMS sustainment. The challenges faced during the installation and certification of stations, supporting States Signatories in sustaining auxiliary seismic stations, as well as issues in the recapitalization of hydroacoustic stations were noted. The panel concurred that the IMS requires a robust budget to ensure its continued operation and improvement. They agreed that the inclusion of failure analysis and learning from other network operators and suppliers, including addressing obsolescence, would be beneficial. The necessity to expand the Database of the Technical Secretariat to include probability statistics and failure data as well as budget information was underscored. The discussion underlined the enduring relevance of IMS, its successful growth despite early challenges, and the vital importance of continuous adaptation and improvement in the face of future operational and technological hurdles.

SE-6 National Data Centres for All Initiative (NDCs4All)

Reference: SE-6-926

A presentation and open discussion took place during SnT2023 on the National Data Centres for All (NDCs4All) initiative, whose purpose is to ensure equal distribution of CTBT benefits among States Signatories and to help them to receive IMS data and IDC products.

WS-1 Workshop on Metrology

References: WS-1-921 and WS-1-920

The purpose of the workshop on metrology was to disseminate outcomes from the European funded project on "metrology for low-frequency sound and vibration" or Infra-AUV. One of the main objectives of the project is to investigate the value of robust calibration practices in sensor networks and the associated practical aspects for maintaining sensor systems. The project produces a recommended good practice guide for establishing traceability through the on-site calibration of sensor systems as one of its outputs. In the context of the CTBTO, the role of metrology is to improve confidence in IMS measurements.

At SnT2023, the workshop on metrology took place over two sessions on 21 and 22 June 2023. The first session focused on developments in laboratory calibration and the second session covered field metrology. Each session attracted around 50 participants, most of whom were involved in some way with CTBTO monitoring, including sensor manufacturers, station operators and CTBTO personnel.

Appendix 3

Exhibitions and Sponsors

Appendix 3

Exhibitions and Sponsors

PTS Exhibitions

IMS Seismic-Infrasound Exhibits

The IMS Division stand presented e-posters with pertinent photographs of installations at IMS infrasound, seismic and radionuclide stations. Mock-up representations of those stations were also displayed, allowing the visitors to familiarize themselves with the layout and the specific systems deployed at the stations. Several video presentations were shown in loop, illustrating maintenance activities performed in recent t years at some IMS infrasound stations.

IMS Hydroacoustic Exhibits

The SnT2023 hydroacoustics technology display desk included:

- A glass cabinet with 17 different types of underwater cables varying from light armoured shallow water fibre optic cables to deep water heavy armoured trunk cables; Most of these cables have been used in hydrophone stations of the IMS.
- A miniature model of a cabled hydroacoustic station with interactive features that light up specific parts of the station.
- Information leaflets and publication articles on IMS hydroacoustics.

In addition, it included a large screen with video presentations on

- IMS hydrophone station installations,
- Underwater equipment such as hydrophones,
- Cable ships employed during installations,
- Underwater diver inspections,
- Educational videos explaining sound propagation in the oceans.

Procurement Services

The exhibit hosted by the Procurement Services Section of the Division of Administration, was the first of this type of outreach at an SnT conference and served as a forum for Procurement staff to interact with suppliers, conference participants and other counterparts. The Procurement team offered leaflets, virtual information and dedicated in-person sessions about how suppliers can register in the procurement roster and participate in CTBTO business opportunities. The exhibit contributed to one of the core procurement strategic outreach efforts to increase direct engagement with the supply market and counterparts seeking to expand the supplier base of the PTS, gain exposure to the latest market trends and technological developments and foster a more dynamic, modern, diverse and effective procurement for the Secretariat. The exhibit further provided an opportunity for the Procurement Services Section to optimize its collaboration channels with internal and external stakeholders for efficient and timely service delivery towards a successful SnT2023.

Human Resources Service

The Human Resources Services team greeted SnT participants at a booth located on the first floor of the Hofburg as part of an effort to inform and cultivate potential candidates with scientific and technical expertise to consider careers with the CTBTO. The team engaged with SnT participants about employment opportunities and the steps in the recruitment process. At the booth, further information was provided through a video featuring senior CTBTO officials highlighting the kinds of talent the organization needs, eye-catching banners, direct online access to the CTBTO jobs portal, and takeaway cards with 10 tips for navigating the recruitment process. During the SnT week, the following hybrid presentations were delivered by Human Resources Services recruitment experts who also answered questions from the audience:

- Two one-hour presentations "Working at the CTBTO Recruitment Session",

- One presentation about employment opportunities for young professionals.

Public Information

The Public Information Section hosted a booth that included printed informational material in all six official languages. This included brochures on the verification regime, civil and scientific applications and OSI as well as a factsheet about the PTS.

OSI

The OSI Division unveiled a new immersive exhibition entitled "OSI Observables: A Virtual Reality Experience" which featured virtual reality tours showing the former Semipalatinsk nuclear test site, a tour of a typical OSI base of operations and a visual observation mission at a former mining area. The exhibition utilized cutting edge virtual reality headsets which provided users with an interactive first person perspective of the virtual reality resources.

OmniGlobe

The PTS interactive OmniGlobe displays animations that introduce CTBTO and its verification regime. This includes:

- The radioxenon background animation that shows the atmospheric concentrations of radioxenon coming from 50 known nuclear sources,
- The updated REB events animations that show all reviewed events that have occurred over 23 years,
- The updated history of the IMS that shows all the certified stations from the different technology,
- The updated Tsunami Warning Centres animation that shows an event location and the data being sent to the 20 Tsunami Warning Centres that have signed the agreement.

Noble Gas Exhibit

Noble gas exhibit. An interactive radioxenon plume simulation with water vapour was mounted on a table. Plumes were released from eight nozzles between the table surface and a plexiglass cover under which an airstream was blowing the plume from the sources to the other end of the table. The release of plumes could be triggered and modified by participants pushing buttons. The audience had a chance to make their own experience with the challenge of distinguishing a specific radioxenon source like a nuclear test from the normal background releases. They were encouraged to explore how easy or how difficult is it to disguise an added signal. The audience became inspired by watching how the plumes move, expand, dilute, and mix. Participants discussed with each other what may be done to enhance the chances of identifying the release event signal.

External Exhibitors

Twenty-five commercial and non-commercial organizations worldwide presented their exhibits at the SnT2023, showcasing new world-class products and technologies. The exhibitors' booths were organized by the domains relevant to CTBTO activities and verification regime.

Domain 1. Sensors and Monitoring Systems

1. GAIACODE Ltd. UK
2. Güralp Systems Ltd.
3. L3Harris - MariPro
4. REFTEK SYSTEMS
5. SEISMOWAVE

Domain 2. Software Solutions and Monitoring and Analysis Services

6. International Seismological Centre
7. Instrumental Software Technologies, Inc.
8. Seismological Society of America
9. Sonicona

Domain 3. Sampling Related Products and Systems

10. Baltic Scientific Instruments
11. F&J SPECIALTY PRODUCTS, INC.

12. Kinemetrics, Inc.
13. Tracerco Ltd

Domain 4. Systems Engineering, Integration and Advanced Manufacturing

14. Cegelec Défense
15. Source Term Analysis of Xenon (STAX) – PNNL
16. Teledyne Brown Engineering, Inc

Domain 5. Monitoring and On-Site Inspections

17. ATOMTEX SPE
18. CAEN SpA
19. Canberra Packard Central Europe GmbH
20. IGI
21. MEET Instruments GmbH
22. MIRION TECHNOLOGIES
23. ORTEC - AMETEK

Domain 6. Building Communities of Scientists and Technical Professionals Working on Monitoring and Verification of the Comprehensive Nuclear-Test-Ban Treaty

24. Pacific Northwest National Laboratory – Outreach
25. Young Professionals Network

Sponsors

EU Delegation, NORSAR and eight companies sponsored the catering events at the SnT2023 Conference.

1. EU Delegation
2. ATOMTEX SPE
3. Baltic Scientific Instruments
4. CAEN SpA
5. Cegelec Défense
6. Kinemetrics, Inc.
7. L3Harris – MariPro
8. MEET Instruments GmbH
9. NORSAR
10. ORTEC - AMETEK

Appendix 4

Statistics

Appendix 4

Statistic

All statistical information on the SnT2023 conference refers to actual presentations given during the conference. Submitted abstracts for which no presentations were given or for which no files were uploaded are not included in the tables below.

Number of Participants

The number of participants in SnT conferences has continued to increase, with 2028 participants in 2023. Table 4.1a presents the number of participants and gender distribution since SnT2015.

Table 4.1a Participation in Science and Technology Conferences since 2015

Year	Mr	Mx	Ms	Total	Mr (%)	Mx (%)	Ms (%)
SnT2015	518	-	182	700	74%	-	26%
SnT2017	621	-	279	900	69%	-	31%
SnT2019	617	-	583	1200	51%	-	49%
SnT2021	1119	12	527	1659	67%	0.7%	32%
SnT2023	**1307**	**5**	**716**	**2028**	64%	0.2%	35%

Number of Participants by Mode of Participation

The increase in the number of participants from SnT2019 to SnT2023 is in part due to the use of a hybrid mode of engagement via an on-site and online experience. Table 4.1.b provides an overview of the number of participants by mode of participation.

Table 4.1b Participation in Science and Technology Conferences since 2015

Year	On-site	Online	Total	On-site (%)	Online (%)
SnT2015	700	0	700	100%	0%
SnT2017	900	0	900	100%	0%
SnT2019	1200	0	1200	100%	0%
SnT2021	250	1409	1659	15%	85%
SnT2023	**1585**	**443**	**2028**	78%	22%

Regional Distribution of Participants

Table 4.2 presents an overview of the regional distribution of participants at SnT2019, SnT2021 and SnT2023. Since the online participation format was introduced in 2021, there has been a large percentage increase for the four regions that previously had the smallest percentage. This is clear evidence of enhanced inclusion and broadening of the geographic coverage. Please note that international organizations, including the CTBTO, were not properly accounted for at the registration of SnT2021. For a portion of participants from international organizations the registration was recorded under their country of residence.

Table 4.2. Regional Distribution of Participants at SnT2019, SnT2021 and SnT2023

Region	SnT2019 (%)	SnT2021 (%)	SnT2023 (%)
Africa	6.6	16.5	15.1
Eastern Europe	8.4	9.3	7.6
Latin America and the Caribbean	3.5	7.8	7.8
Middle East and South Asia	5.7	12.4	12.4
North America and Western Europe	**57.1**	**41**	**33.2**
South East Asia, the Pacific and the Far East	**5.6**	**10.4**	**9.8**
International Organizations	**13**	**2.5**	**14.0**

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 used this format to feature topics of high interest and future relevance with panellists solicited by the CTBTO. Table 4.3 presents an overview of the number of panel discussions since SnT2015.

Table 4.3. Number of Panel Discussions at SnT Conferences since 2015

Year	Number of Panel Discussions
SnT2015	7
SnT2017	9
SnT2019	19
SnT2021	11
SnT2023	**16**

Distribution of Panellists by Geographical Region and Gender

The panellists at SnT2023 came from all geographical regions, reflecting the diversity of the participants at the conference. Table 4.4 demonstrates the number of SnT2023 experts that appeared as panellists, moderators and invited speakers by geographical area and gender in SnT2019, SnT2021 and SnT2023. In some cases, the same expert appeared in more than one role. At SnT2023, gender parity was almost achieved with 47% of all experts appearing on stage being women. The experts from North America and Western Europe have by far the largest share. Attempts to increase the share of experts from other regions was partially successful.

Table 4.4 Distribution of Appearance (On Stage) of SnT2023 Panellists, Moderators and Invited Speakers by Geographical Region and Gender at SnT2019, SnT2021 and SnT2023

	Gender Distribution by Region at SnT2023					Geographical Distribution Development Since SnT2019		
Region	Ms	Mr	Total	Ms (%)	Mr (%)	SnT2019 Share (%)	SnT2021 Share (%)	SnT2023 Share (%)
Africa	8	12	20	40%	60%	9	13.6	18.9
Eastern Europe	2	1	3	67%	33%	7	5.1	2.8
Latin America and the Caribbean	8	5	13	62%	38%	11	11.9	12.3
Middle East and South Asia	3	3	6	50%	50%	5	1.7	5.7
North America and Western Europe	22	24	46	48%	52%	44	50.8	43.4
South East Asia, the Pacific and the Far East	1	4	5	20%	80%	11	16.7	4.7
International Organizations	1	4	5	20%	80%	12		4.7
VIC	5	3	8	63%	38%			7.5
Total	**50**	**56**	**106**	**47%**	**53%**	**100**	**100**	**100**

Abstracts, Oral and Poster or E-Poster Presentations

A powerful value of SnT conferences is derived from the individual presentations under each theme. Authors submitted abstracts of their presentations which were accepted by the programme team after careful review. Table 4.5 summarizes the number of oral and poster (or e-poster) presentations at SnT conferences since 2015. The number of oral presentations is dictated by the limited time during the week of the conference. Therefore, the number remains stable for the recent SnT conferences at around 100. Also, Table 4.5 numbers include orals that are part of Themes and Topics or special sessions, but they exclude Invited Talks and Highlight Talks. The number of posters was also quite stable, at around 340 until 2019, which seemed to indicate that the SnT conferences had exhausted their outreach. However, the introduction of the remote online presentation opportunity for e-posters resulted in a reduced number of withdrawals, which occurred before the conference as a consequence of the inability of authors to travel to the conference venue. At SnT2023, the number of e-posters increased by 34% compared to the base line.

Table 4.5. Number of Oral and Poster/E-Poster Presentations at SnT Conferences since 2015

Year	Oral*	Poster/E-Poster
SnT2015	80	320
SnT2017	100	340
SnT2019	118	342
SnT2021	108	365
SnT2023	**101**	**455**

*This figure includes oral presentations under Themes and Topics and talks from special session (such as PTS talks at SnT2023).

Table 4.6 shows the distribution of SnT2023 oral presenters by geographical region and gender. Almost all oral presentations were given live at the Hofburg Palace and there were only five exceptions of pre-recorded video presentations. 45% are from North America and Western Europe (63% at SnT2021), while the other regions have kept or increased their share significantly to get close to 10%, except for one region that remains at 5%.

Table 4.6. Distribution of SnT2023 Oral Presenters by Geographical Region and Gender

Region	Total	Share by Region (%)	Ms	Mr	Ms (%)	Mr (%)
Africa	12	10.9%	4	8	33%	67%
Eastern Europe	6	5.5%	1	5	17%	83%
Latin America and the Caribbean	9	8.2%	1	8	11%	89%
Middle East and South Asia	8	7.3%	3	5	38%	63%
North America and Western Europe	51	46.4%	17	34	33%	67%
South East Asia, the Pacific and the Far East	11	10.0%	3	8	27%	73%
International Organizations	13	11.8%	4	9	31%	69%
Total (absolute numbers)	**110***	**100%**	**33**	**77**	30%	70%

*This figure includes oral presentations under Themes and Topics, Invited Talks preceding panel discussions and PTS talks.

At SnT2023, e-posters were presented by uploading digital e-poster files, by providing a short lightning talk in most cases as a live presentation, otherwise with prerecorded videos, and most importantly, with the author in attendance at sessions. In addition, e-poster presenters could participate in an online e-poster discussion session to briefly summarize and discuss the highlights of their e-posters. The e-posters could be viewed any time before, during or after the conference on the SnT2023 event portal. Table 4.7. shows the distribution of SnT2023 e-poster presenters by geographical region and gender. The share of regions is similar to the oral presentations and the share of women is 24%. The objective of gender balance was one of the criteria applied when selecting speakers and the share of oral presentations by women authors increased to 30%.

Table 4.7. Distribution of SnT2023 E-Poster Presenters by Geographical Region and Gender

Region	Total	Share by Region (%)	Ms	Mx	Mr	Ms (%)	Mr (%)
Africa	46	10.1%	9	0	37	20%	80%
Eastern Europe	29	6.4%	9	1	19	31%	66%
Middle East and South Asia	43	9.5%	18	0	25	42%	58%
North America and Western Europe	177	38.9%	36	0	141	20%	80%
South East Asia, the Pacific and the Far East	52	11.4%	18	0	34	35%	65%
International Organizations	68	14.9%	11	0	57	16%	84%
Total	**455**	**100%**	**109**	**1**	**345**	**24%**	**76%**

Themes and Topics

Table 4.8. provides the number of oral and e-poster presentations by Themes and Topics. The number of presentations by Topic varies between 6 and 53.

Table 4.8. SnT2023 Oral Presentations According to Theme and Topic

Theme and Topic	Oral Presentations	E-Poster Presentations
Theme 1: The Earth as a Complex System	21	89
T1.1 The Atmosphere and its Dynamics	5	20
T1.2 The Solid Earth and its Structure	9	44
T1.3 The Oceans and Their Properties	3	12
T1.4 Multidisciplinary Studies of the Earth's Subsystems	4	13
Theme 2: Events and Nuclear Test Sites	20	111
T2.1 Characterization of Treaty-Relevant Events	5	17
T2.2 Challenges of On-Site Inspection	2	6
T2.3 Seismoacoustic Sources in Theory and Practice	5	26

T2.4 Atmospheric and Subsurface Radionuclide Background and Dispersion	5	47
T2.5 Historical Data from Nuclear Test Monitoring	3	15
Theme 3: Monitoring and On-Site Inspection Technologies and Techniques	21	135
T3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications	3	20
T3.2 Radionuclide Technologies and Applications	3	22
T3.3 On-Site Inspection Techniques	4	25
T3.4 Integrating Data from Different Monitoring Technologies	0	6
T3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data	6	41
T3.6 Analysis of Radionuclide Monitoring Data	5	21
Theme 4. Sustainment of Networks, Performance Evaluation, and Optimization	16	55
T4.1 Performance Evaluation of the International Monitoring System and On-Site Inspection and their Components	4	12
T4.2 Systems Engineering for International Monitoring System and On-Site Inspection	3	12
T4.3 Enabling IT Technologies	2	11
T4.4 International Monitoring System Sustainment	3	8
T4.5 On-Site Inspection Team Functionality	4	12
Theme 5. CTBT in a Global Context	18	64
T5.1 CTBT Science and Technology Policy	3	5
T5.2 Synergies with Global Challenges	6	24
T5.3 Regional Empowerment	5	20
T5.4 Outreach	4	15