SnT 2019
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

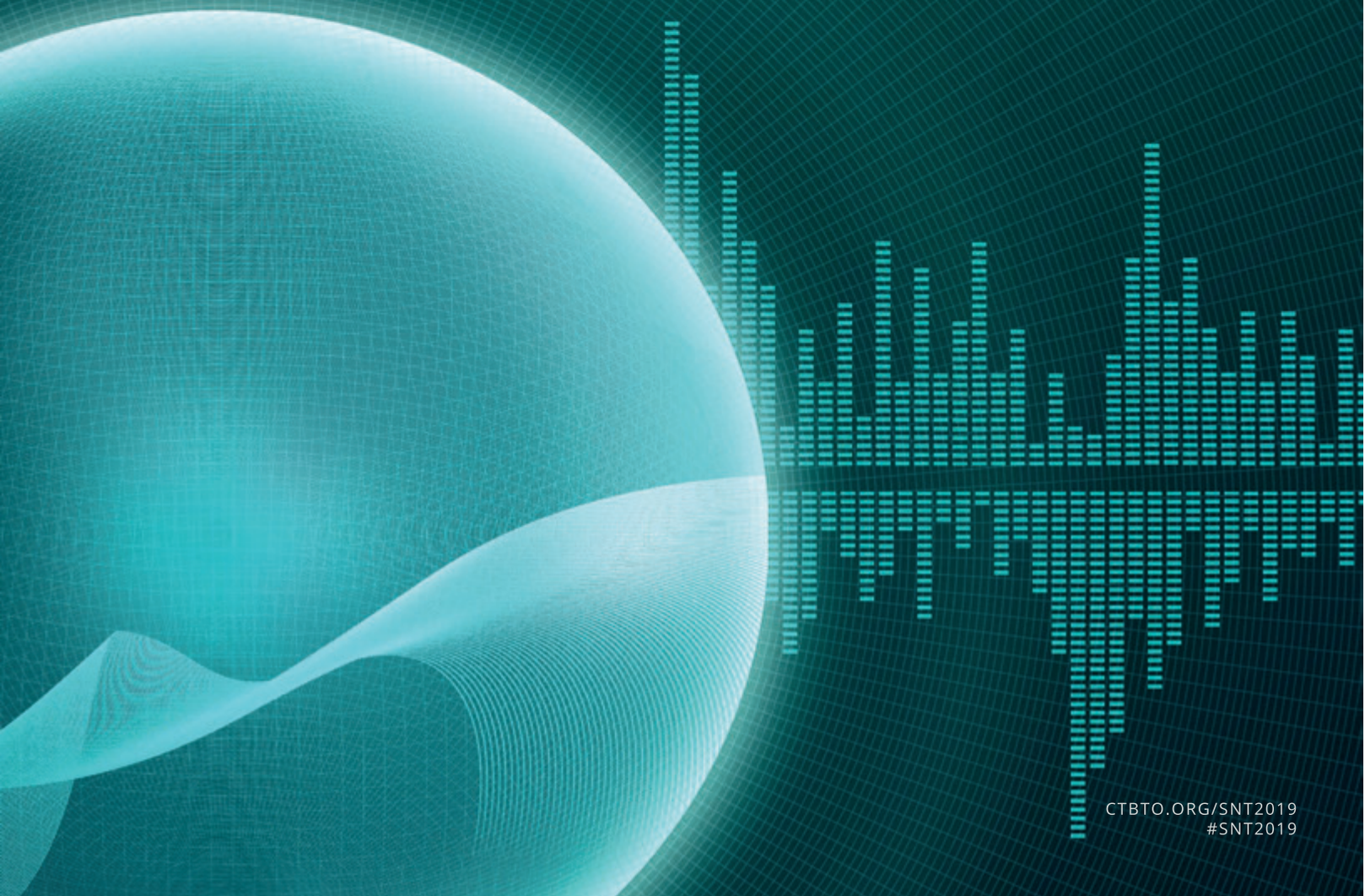
CTBTO
PREPARATORY COMMISSION

Scientific Advances in CTBT Monitoring and Verification 2019

Review of Presentations and Outcomes of the Comprehensive Nuclear-Test-Ban Treaty: Science and Technology 2019 Conference

24 TO 28 JUNE

HOFBURG PALACE
VIENNA, AUSTRIA



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Scientific Advances in CTBT Monitoring and Verification 2019

Review of Presentations and Outcomes of the
Comprehensive Nuclear-Test-Ban Treaty:
Science and Technology 2019 Conference

24-28 June 2019, Hofburg Palace, Vienna

CONTENTS

LIST OF FIGURES

CTBT: Science and Technology Conference Series

In order to build and strengthen its relationship with the broader science community in support of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) invites the international scientific community to conferences on a regular basis. SnT2019 was the fifth such conference since 2011.

These conferences contribute to a process whose aim is to ensure that the verification regime of the CTBTO can benefit from current scientific and technological developments in relevant fields. The Conference Goals define the scope of topics covered in greater detail.

These multidisciplinary scientific conferences attract scientists and experts from a broad range of CTBT verification technologies, from national agencies involved in the work of the CTBTO to independent academic and research institutions. Members of the diplomatic community, international media, civil society and youth also take an active interest.

SnT2019 was held in the Hofburg Palace in Vienna, Austria, on 24-28 June 2019. This report provides an overview of the scientific contributions presented at the conference and identifies some highlights and potential focus areas for the future.

The Preparatory Commission and the Comprehensive Nuclear-Test-Ban Treaty Organization

The Preparatory Commission for the CTBTO was established by Resolution CTBT/MSS/RES/1, which was adopted by the States Signatories to the CTBT on 19 November 1996. It was established to prepare for the entry into force of the Treaty and to build up the functionality specified therein, including the International Monitoring System (IMS) and the International Data Centre (IDC). Its secretariat is referred to as the Provisional Technical Secretariat (PTS). After entry into force, the Preparatory Commission will be replaced by the CTBTO, as specified in the Treaty, and the PTS will be replaced by the Technical Secretariat. For simplicity, the term 'CTBTO' is generally used in this report to refer to both the current and future organizations, except where it is important to distinguish between the two.

Disclaimer

The views expressed are those of the authors and do not reflect the positions or policies of the Preparatory Commission for the CTBTO.

Abbreviations

ARISE	Atmospheric dynamics Research InfraStructure in Europe project
AS	auxiliary seismic (station)
ATM	atmospheric transport modelling
CTBT	Comprehensive Nuclear-Test-Ban Treaty
CTBTO	Comprehensive Nuclear-Test-Ban Treaty Organization
HA	hydroacoustic (station)
IDC	International Data Centre Division
IMS	International Monitoring System Division
IS	infrasound (station)
NDC	National Data Centre
OSI	On-Site Inspection (Division)
PS	primary seismic (station)
PTS	Provisional Technical Secretariat
RN	radionuclide (station)
RSTT	regional seismic travel time
SDG	United Nations Sustainable Development Goal
SnT	CTBT: Science and Technology conference
SSI	standard station interface
UNE	underground nuclear explosion
vDEC	Virtual Data Exploitation Centre
WCC	waveform cross-correlation
WGB	Working Group B

Opening Remarks from the Executive Secretary of the Preparatory Commission for the CTBTO

President Fischer,
Minister Rauskala,
Honourable Ministers and Vice-Ministers,
Rector Polanco,
Excellencies,
Ladies and Gentlemen,

It gives me great pleasure to welcome you to the CTBT: Science and Technology 2019 conference, the fifth in our series of conferences.

This year, as in previous years, we have brought together scientists, industry leaders, policymakers, civil society and academia from around the world to exchange knowledge and share advances in the monitoring and verification technologies relevant to the Comprehensive Nuclear-Test-Ban Treaty.

SnT2019 is the biggest ever. Participant figures are still being compiled, but thus far it looks like we have more registrations than ever before. This is one of the reasons why we moved the opening ceremony and a number of panel discussions here to the Festsaal of the Hofburg Palace, which I am sure you will agree looks amazing today.

As you can see from the conference programme, there is a lot in store this week, with panels, sessions and special events covering the nexus of CTBT science, technology and policy. These are spread across five themes: the Earth as a Complex System, Events and Nuclear Test Sites, Verification Technologies and Technique Application, Performance Optimization, and the CTBT in a Global Context.

I will mention some of the innovations in this year's conference in just a moment, but first I wish to acknowledge some of the most important people in ensuring the flow of CTBT data over the years: the operators of our International Monitoring System stations and their staff. Working at hundreds of stations across the globe, and often in fairly inaccessible locations, these people are the backbone of nuclear test monitoring and detection. Without them, there would simply be no International Monitoring System.

We are joined today by the caretaker of one such station, Ms Sanni Mäkelä-Vesa. Sanni looks after the PS17 array in Sysmä, Finland, one of the 50 primary seismic stations in our network.

PS17 is located in the middle of a dense forest, quite a distance from Helsinki, where the station operator, the Institute of Seismology at the University of Helsinki, is based. Sanni is far too modest to admit how important she is. But if the signal from our otherwise unmanned stations cuts out, it is Sanni and people like her who takes direct action to bring it back online.

I am delighted that Sanni – and her daughter – could be with us today. Thank you for all you have done and continue to do to make the world a more peaceful, more secure, place. I invite all participants to give a round of applause to Sanni and all the unsung heroes of the International Monitoring System.

I also want to thank all of the Permanent Representatives to the CTBTO, past and present, for their dedication. A number of those who are here today will soon see their current postings come to an end. Ambassador Shin Dong-Ik of the Republic of Korea has just left Vienna for fresh challenges, but his tireless work will not be forgotten. I am certain that his designated successor, Ambassador Dato' Ganeson Sivagurunathan of Malaysia, will 'take the ball and run with it'.

Now, looking more closely at the programme, you will notice many exciting elements that appear for the first time. I would like to recognize the 'blue sky thinking' and hard work put in by the Project Executives of this year's conference: Nurcan Meral Özel, Director of the International Monitoring System Division, and Tammy

Taylor, Director of the International Data Centre Division. Together with a team from across the whole of the organization, they have added a fresh touch to SnT2019.

Youth engagement was introduced as an essential element at the last SnT conference in 2017, and this year it is more strongly integrated than ever. This afternoon's Youth Forum, held jointly with the Ban Ki-moon Centre for Global Citizens, will put young people front and centre as they tell us what needs to be done to achieve peace and security.

Two panel discussions today will be held entirely in the French and Spanish languages. This is in keeping with our determination to 'walk the talk' on multilingualism in our organization.

Tonight, we will have our first ever evening session, a lively panel on Women in Science and Technology, which will be followed by a reception. Another evening session, entitled "Getting the Non-Proliferation and Disarmament Architecture Back on Track", will be held tomorrow, just after the reception sponsored by the European Union. I hope to see many of you there.

Ladies and Gentlemen,

The high level opening this morning features eminent speakers and discussants. There is a strong host country presence: We are honoured to have Minister Iris Rauskala, Austrian Federal Minister for Education, Science and Research, present to deliver words of welcome. Austria has always been a firm friend of the CTBT and of this conference series.

Our first keynote address today comes from a man who is no stranger to most: former President of Austria, Dr Heinz Fischer.

As you will have seen in the programme, the eighth Secretary-General of the United Nations, Mr Ban Ki-moon, was the announced keynote speaker. Due to the sad passing of Mr Ban's mother a few days ago, he is unable to join us in Vienna. However, we are delighted that Dr Fischer, who is co-chair of the Ban Ki-moon Centre for Global Citizens, will deliver the address on his behalf.

I also wish to thank Professor Sir Mark Welland, Master of St Catharine's College, University of Cambridge, for being here to deliver this year's scientific keynote. Sir Mark has a wealth of experience in the application of science to policymaking, and we look forward to what will undoubtedly be an interesting and illuminating address.

Our panel this morning, entitled "CTBT: Science and Technology in a Changing World", will provide a link to many of the themes and issues under consideration during the course of the week.

United Nations Under-Secretary-General and High Representative for Disarmament Affairs, Ms Izumi Nakamitsu, will join us together with Professor Romain Murenzi from The World Academy of Sciences and Professor Jennifer Thomson of the Organization for Women in Science for the Developing World.

Between them there will be a lot to discuss, from how the CTBT can advance nuclear non-proliferation and disarmament and science diplomacy to how barriers to participation in science can be overcome.

Excellencies,
Ladies and Gentlemen,

As we look at the world today, I understand very well the temptation to give in to cynicism where nuclear non-proliferation and disarmament is concerned. But the message I want this conference to deliver is that there is good news to share and there are valuable assets we can build on.

Today, there are over 300 International Monitoring System installations positioned around the globe, sending data to the International Data Centre in Vienna. In fact, the CTBTO already provides a level of nuclear test detection capability that few thought would be possible when the Treaty was first negotiated.

Over 90% of CTBT facilities have been built and transmit data, allowing States Signatories to draw an independent conclusion on the nature of events picked up by the system and ultimately determine whether a nuclear explosion has occurred. This corresponds to approximately 14 terabytes of data per year, making the CTBT second to none when it comes to monitoring – and better understanding – our planet.

The strong performance of the verification regime for nuclear test monitoring and other purposes is borne out by the abstracts, posters and oral presentations to be made here this week. This clearly demonstrates that the CTBT is not a theoretical treaty: it has a real impact.

Signatures and ratifications continue to accrue. With Zimbabwe ratifying recently, the Treaty now has 184 States Signatories, of which 168 have ratified. Meanwhile, the opening of our new Technology Support and Training (TeST) Centre in Seibersdorf, Austria, which was made possible by the generous support of States Signatories, shows that the organization is here for the long haul.

Still, more needs to be done. Delivering on the CTBT is key to rebuilding the trust needed for the way ahead.

Action on the Treaty would provide the progress we need to see in the run-up to next year's Review Conference for the Treaty on the Non-Proliferation of Nuclear Weapons. Given that CTBT verification is up and running and that there is a de facto global moratorium on nuclear tests, entry into force is the most effective disarmament measure within the grasp of the international community.
Let us not be distracted by cynicism. All States have the responsibility to pass on the hard-won gain of the CTBT to future generations.

The discussions over the next few days will focus on CTBT technologies and their various applications. However, we should never forget that this is one part of a bigger prize.

The progress that we make on locking in the nuclear test ban, on both the scientific and diplomatic fronts, will determine how successful we are in reaching our ultimate goal of making the world more safe, secure and prosperous.

Thank you.


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Federica MOGHERINI
High Representative / Vice-President of the European Commissio

Welcome from the Host Country

Iris Rauskala
Federal Minister of Education, Science and Research

Dear Executive Secretary Dr Zerbo,
Dear President Fischer,
Dear Ministers,
Excellencies,
Ladies and Gentlemen,

It gives me great pleasure to be present at the Hofburg Palace today and participate in this high level opening of the fifth CTBT: Science and Technology conference. It looks as if the success of the previous conference in 2017 with some 1000 participants will be outdone this year. Congratulations!

As Austria's Federal Minister of Science, I am particularly happy to be here not only representing a Member State of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization and the organization's host State, but also as the representative of a country that fervently supports nuclear disarmament and non-proliferation.

Lately, the nuclear disarmament and non-proliferation community has not exactly been spoilt for good news: Nuclear power competition is increasing, established channels of communication are breaking down and investments in arsenals are on the rise, as are boasts about the development of new, ever more terrible weapons. Even existing disarmament progress is being reversed or questioned.

We have to fight these disastrous tendencies, and the CTBTO should be at the forefront of this battle for preventing the proliferation of nuclear arms.

In this context I may refer, somewhat proudly, to the new CTBTO TeST Centre that was recently opened in the presence of Austrian and foreign dignitaries in Seibersdorf in Lower Austria. The Austrian Government is very pleased indeed that CTBTO has chosen the site next to the Austrian Institute of Technology and the Seibersdorf Laboratories for this very major infrastructure investment.

Today, I believe everyone agrees that we have another reason to celebrate, as this conference gives an outstanding example of the CTBTO's efforts to reach out and promote the wider civil and scientific applications of techniques and data used for test ban verification.

The conference takes place against the background of the enormous achievements of the CTBTO Preparatory Commission and the Provisional Technical Secretariat in having brought the CTBT verification system to a degree of readiness of well over 90%, even before the entry into force of the Treaty.

The data delivered by the system was crucial in ensuring the unified reaction of the international community in condemning nuclear tests by the Democratic People's Republic of Korea.
And let us not forget the civil and scientific benefits that can derive from the techniques and data used for test ban verification. The efficacy of the International Monitoring System has proven key to detect and combat the consequences of natural disasters like tsunamis and earthquakes.

On the way forward, it will be necessary to strengthen even more the engagement of the scientific communities working in test ban monitoring, especially of young scientists.

Let me quote the Executive Secretary, who stated that this conference facilitates the articulation of new ideas and technologies that are essential for promoting global peace and security. Together, we must try to continuously improve nuclear test monitoring and verification.

Vienna's Hofburg Palace is among the world's most attractive conference locations. I am confident that you all, dear participants, whether you are well established or still young scientists, industry leaders, media representatives or policymakers, will find the Hofburg atmosphere and the Vienna spirit beneficial for your lively discussions and scientific deliberations during the next five days.

In this spirit, I wish this conference and all its sessions numerous beneficial results.

May your work bear fruit and help us along a path of continuous progress towards the entry into force of the Comprehensive Nuclear-Test-Ban Treaty and, eventually, to reaching our common goal of eliminating the threat of nuclear weapons.

Thank you.

1. Introduction

Introduction

Purpose of This Report

This report contributes to the written archive of progress made in Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification science and related activities presented as part of the Science and Technology (SnT) conference series process. As such, its intended audience comprises the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) as well as all those who are active in the field 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.

This report aims to help facilitate the assessment of progress in implementing ideas presented at the CTBT: Science and Technology 2019 (SnT2019) conference and to foster new work among the concerned community of scientists. It will be uploaded to the SnT web page of the CTBTO public web site, where the abstracts, conference programme, oral and poster presentations, video recordings and other material related to this and all previous SnT conferences can be found, together with reports on previous SnT conferences. 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 will allow 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.

CTBT: Science and Technology Conferences as a Continuous Process

SnT conferences are part of a continuous process of engaging the global scientific community. 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 takes into account the Treaty's recognition that it may be appropriate to have a formal mechanism after entry into force to solicit external scientific advice on the enhancement of the technical capabilities of the verification regime. Many 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 ideas may make their way through development and testing, with a view to being incorporated into provisional operations at the CTBTO. In other cases and in light of Treaty provisions, it may be more appropriate for States Signatories to develop technologies in support of their own verification efforts. With a focus on the particular needs of the CTBT verification regime, specific contributions are identified accordingly in the Highlights section under each topic in Chapter 3 and each panel in Chapter 4.

Conference Goals and Themes

Conference Goals

SnT2019 had five goals:

- To broaden and strengthen the engagement of the scientific communities working in test ban monitoring, including young scientists, and to enhance the geographic and gender representations of these communities;
- To support the exchange of knowledge and ideas between the CTBTO and the broader scientific community;
- To identify opportunities and possible solutions to continuously improve nuclear test monitoring and verification;
- To identify how scientific developments and cooperation can support national needs and frame policy objectives in support of the CTBT;
- To promote the wider civil and scientific applications of techniques and data used for test ban verification.

These goals expand upon the four goals of SnT2017 in three ways: the first goal places further emphasis on the enhancement of geographical and gender representation, the newly added fourth goal addresses the purpose to support national needs and to frame policy objectives in support of the CTBT, and the last goal now includes civil applications.

Conference Scientific Themes and Topics

SnT2019 focused on the five scientific themes listed below. Several topics were identified under each theme. Authors were required to submit each of their abstracts under one of the topics. Oral and poster presentations were invited under each topic.

Theme 1. The Earth as a Complex System

T1.1 Atmospheric Dynamics
Chairs: Elisabeth Blanc, Pierrick Mialle
T1.2 Solid Earth Structure
Chairs: Alik Ismail-Zadeh, Paul Richards, Nurcan Meral Özel, Gerhard Graham
T1.3 Properties of the Ocean
Chairs: Bruce M. Howe, Georgios Haralabus, Peter Nielsen
T1.4 Interaction Among the Earth's Subsystems
Chairs: Eugenio Polanco Rivera, Pierre Bourgouin

Theme 2. Events and Nuclear Test Sites

T2.1 Characterization of Treaty-Relevant Events
Chairs: Alexey Malovichko, Ronan Le Bras, Peter Labak
T2.2 Challenges of On-Site Inspection
Chairs: John Walker, Hongmei Deng
T2.3 Seismoacoustic Sources in Theory and Practice
Chairs: Atalay Ayele, Paulina Bittner
T2.4 Atmospheric and Subsurface Radionuclide Background and Dispersion
Chairs: Anders Ringbom, Jolanta Kusmierczyk-Michulec, Boxue Liu, Romano Plenteda
T2.5 Historical Data from Nuclear Test Monitoring
Chairs: Paul Richards, Martin Kalinowski

Theme 3. Verification Technologies and Technique Application

T3.1 Design of Sensor Systems and Advanced Sensor Technologies
Chairs: Yoshiyuki Kaneda, Ricardo Sagarazu, Julien Marty, Nikolaus Hermanspahn
T3.2 Laboratories Including Mobile and Field Based Facilities
Chairs: Christopher Timperley, Robin Riedmann, Naoko Ìnoue
T3.3 Remote Sensing, Satellite Imagery and Data Acquisition Platforms
Chairs: Tim Ahern, Li Hua, Aled Rowlands
T3.4 Augmented Reality and Fusion of Data from Different Monitoring Technologies
Chairs: Zeinabou Mindaoudou Souley, Noriyuki Kushida
T3.5 Data Analysis Algorithms, Artificial Intelligence, Big Data and Deep Learning
Chairs: Kevin Muhs, Ivan Kitov, Hakim Gheddou

Theme 4. Performance Optimization

T4.1 Network Optimization
Chairs: Jay Zucca, David Merker, Hideaki Komiyama
T4.2 Systems Engineering
Chairs: Jean Sciare, David Merker, David Jepsen
T4.3 Enabling Technologies
Chairs: Aristide Aly Boyaram, James Mattila
T4.4 Performance of the Full Verification System
Chairs: Tim Ahern, Thierry Heritier

Theme 5. CTBT in a Global Context

T5.1 Science in Policy Discussions and Lessons Learned from Other Arms Control Agreements and Arrangements
Chairs: Mahlet N. Mesfin, Al-Sharif Nasser Bin Nasser, Cormac O'Reilly
T5.2 Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals
Chairs: Mobolaji Oladoyin Odbubanjo, Francois Schindele, Tammy Taylor
T5.3 Capacity Building, Education and Public Awareness
Chairs: Man-Sung Yim, Gerard Rambolamanana

Related Material

All material mentioned below is available on the SnT event portal https://events.ctbto.org/snt through the Science and Technology conference series link on the CTBTO public web site (www.ctbto.org). The SnT2019 Conference Programme and Book of Abstracts are complementary to this report. This material, as well as information on the Scientific Programme Committee, slides of oral presentations, images of poster presentations and video recordings of all sessions, is available on the dedicated SnT2019 web page https://events.ctbto.org/snt/2019.

Information on previous SnT conferences and reports on SnT conferences are also available on the public web site.

Report Structure

The structure of this report follows the scientific conference programme. At the beginning of the report, the opening speeches (preceding **Chapter 1**) and keynote addresses (**Chapter 2**) from the opening session are reproduced to provide context. The account of scientific contributions (**Chapter 3**) is organized according to the conference themes, and topics within those themes, as listed in **Section 1.3.2**. Chapter 3 contains a brief summary of all oral presentations that were presented, plus all poster presentations for which an electronic file was submitted on the conference registration platform. For each topic, the summary of presentations is preceded by a description of their highlights. The subchapters vary significantly in length. This reflects the distribution of topics covered by submitted abstracts and may by itself indicate areas where effort should be invested to encourage more active interest in the external scientific community. All panels are represented in **Chapter 4** with a short summary followed by the highlights of the discussions. All closing remarks made during the closing session are presented in **Chapter 5**. The final chapter, on relevance to CTBTO activities and verification science (**Chapter 6**), reviews the conference highlights and discusses potential focus areas for the future. The substructure of Chapter 6 closely follows the main structure of the SnT2017 report by following the logic of the data flow: from data acquisition through data transmission, data processing and analysis, to interpretation. Additional sections cover properties of the earth that are necessary to support verification science, performance monitoring, capacity building and training, as well as policy and advocacy to reflect the introduction of these aspects into the programme. Each of these sections includes relevant material on global monitoring using the IMS, as well as local scale activities for on-site inspection (OSI), and non-CTBTO or novel methodologies as appropriate.

Appendix 1 contains a list of all oral and poster presentations that were presented;
Appendix 2 gives details on the panel discussions;
Appendix 3 presents a selection of the exhibitions, software demonstrations and technical visits;
Appendix 4 lists all members of the Scientific Programme Committee;
Appendix 5 lists all exhibitors and sponsors;
Appendix 6 provides event statistics; and
Appendix 7 provides a tabular overview of network visualizations of countries and institutions.

An index of authors including panel discussion participants and an index of abstract identifiers are provided to facilitate cross-referencing.

HOME
CONTENTS

PAGE NAVIGATION






2. Keynotes

Keynotes

Heinz Fischer (Austria), Former President of Austria (2004-2016), Ban Ki-moon Centre for Global Citizens

Excellencies,
Distinguished Delegates,
Ladies and Gentlemen,

It is an honour and a privilege to be here with you today for this important science and technology forum.

My friend and colleague Ban Ki-moon regrets very much that he cannot be here today. Sad personal circumstances prevented him from coming to Vienna to speak at today's opening ceremony of the Science and Technology conference of the Comprehensive Nuclear-Test-Ban Treaty Organization. Ban Ki-moon asked me to be here in his stead and to speak to you about the important role the CTBTO continues to play for the peaceful and secure cohabitation of this planet.

Ban Ki-moon served as the Chairperson of the CTBTO Preparatory Commission back in 1999. This shows that this organization has been dear to him since the initial years of its existence.

The basis of this keynote speech is the manuscript of Ban Ki-moon, transformed in my language with some of my own personal observations.

The CTBTO remains a shining example of how science and technology can help contribute to positive political and diplomatic outcomes. The Treaty has had a significant positive impact since it was adopted in 1996. With the notable exception of the Democratic People's Republic of Korea, the CTBT has achieved de facto implementation despite not having entered into force, with no other nuclear state having carried out a nuclear test since 1998.

Despite the lack of entry into force, the CTBT and CTBTO have made important contributions in making it easier to detect nuclear tests and in establishing a strong normative taboo against states carrying out nuclear tests. This has made a notable contribution to protecting the world from the deeply harmful environmental and health impacts of nuclear testing, and is an important step on the path towards general and complete disarmament.

All of this has been possible because of the hard work and commitment of a group of scientists and technology experts who nearly 30 years ago undertook intensive, complex and sensitive groundwork to pave the way for a deal. Their efforts made it easier for the diplomats to negotiate the final text, because there was already a scientific and technological consensus on the parameters.

Therefore all of us express our admiration and gratitude for all that this organization has done over the decades to support nuclear non-proliferation and the true cause of peace.

However, I fear it is a bittersweet moment, because today there is an acute risk that rash and hubristic policy shifts could undo all of the valuable work the CTBTO and others have achieved, bringing us closer to the brink of a devastating nuclear war than at any time since the atomic bomb was dropped on Hiroshima and Nagasaki in August 1945.

We currently find ourselves at one of the most dangerous times for arms control efforts for many decades. The bilateral arms control architecture developed between the United States and the Soviet Union towards the end of the Cold War is being rapidly unravelled through a combination of neglect, hubris and erroneous threat analysis. The risk of a catastrophic nuclear event, whether by accident or design, is increased by the paralysis in international bodies charged with upholding peace and security, most notably the United Nations Security Council.

Ban Ki-moon had the honour of addressing the Council earlier this month in New York as a member of The Elders, a group of independent leaders founded by Nelson Mandela who work for peace, justice and human rights. Together with Mary Robinson, he spoke frankly to the Council and particularly to its five permanent members – all nuclear-armed states – to remind them of their uniquely heavy responsibility to develop effective processes of non-proliferation and disarmament.

However, there are only few signs of the P5 and other states with nuclear weapon capabilities showing the will to meet these, as national and international politics appears increasingly driven by polarization, isolationism and an alarming disdain for the very principles of multilateralism.

The imminent expiration of the Intermediate-Range Nuclear Forces (INF) Treaty in August is the most significant blow, with the potential to threaten the stability not only of Europe, but also much of Asia, if it leads to a renewed arms race. The decision of United States President Donald Trump to withdraw from the INF is symptomatic of a much broader negative context of unilateral moves and repudiation of previous agreements.

Consider the possible collapse of the Joint Comprehensive Plan of Action, an agreement negotiated so painstakingly here in Vienna, and which was universally deemed to be working well before the American decision, with all the implications we see now for rising tensions.

Consider as well the recent United States withdrawal from the Arms Trade Treaty and growing concern as to whether the New START Treaty between the United States and the Russian Federation will be extended beyond February 2021.

The world needs to wake up to the severity of the current threat, and the nuclear states must get serious about taking steps towards disarmament to avert an incalculable catastrophe. Nuclear weapons constitute an existential threat to the future of humanity, just as much as climate change.

And just as science plays an indispensable role in the fight against climate change, so it must now be mobilized in the service of nuclear disarmament and non-proliferation. This includes exact and dispassionate analysis of new technological developments that risk complicating and destabilizing traditional practices of arms control and disarmament, including artificial intelligence, cyber-technology and space-based delivery and tracking systems.

In the longer term, total disarmament is likely to require the multilateral agreement of a Nuclear Weapons Convention. This may seem a remote prospect today, but in order for such a convention to be a realistic possibility in the future there is an important need for substantial work to be done now to find technological solutions that can enable total disarmament to take place with confidence that effective verification and enforcement mechanisms are in place.

All of us need to treat these issues with the utmost seriousness and urgency.

This is why The Elders have launched a new initiative on nuclear non-proliferation and disarmament, which was presented by Mary Robinson and Lakhdar Brahimi to the Munich Security Conference this February. They are calling on the nuclear powers to pursue a "minimization agenda" that could help to reduce the nuclear threat and make concrete progress towards disarmament.

Nuclear states should and must make progress in four areas:

Doctrine – all states making a "no first use" declaration;
De-alerting – taking almost all nuclear weapons off high alert status;
Deployment – dramatically reducing the numbers of weapons actively deployed; and
Decreased numbers – for Russia and the United States to adopt deep cuts in warhead numbers to around 500 each, with no increase in warheads by other states.

Above all, the nuclear states must work to reduce tensions and take practical, concrete steps to demonstrate to the world that they do not intend to keep these weapons indefinitely.

In this regard, it would be a tremendously positive step for the nuclear states to make concrete progress towards finally bringing the CTBT into force. Ban Ki-moon is calling upon the eight remaining Annex 2 States who have not yet ratified the CTBT – six of which possess nuclear weapons – to do so at the earliest opportunity. There is no good reason to fail to sign or ratify this treaty.

Excellencies,
Ladies and Gentlemen,

Steps towards disarmament need to be implemented with the understanding that the binary divide of the Cold War, with Washington on the one side and Moscow on the other, is no longer dominant.

Instead, we live in a world of interlinked nuclear chains, where decisions by one state can have a ripple effect beyond any one immediate strategic environment. The threatened collapse of the INF is a case in point; its demise will not just raise security threats on the European continent but also spark instability and potential strategic escalation in other regions, especially Asia.

The only way to tackle these threats is to internationalize and multilateralize the issue, including via the United Nations and bodies such as the CTBTO. Only by facing this threat together, as a global community, can we hope to find a durable solution.

No country individually, nor the international system collectively, has the capacity to cope with the humanitarian consequences of the use of nuclear weapons.

For the very survival of humanity, nuclear weapons must never be used again, under any circumstances. The only guarantee of the non-use of nuclear weapons is their complete abolition.

We will only reach this goal if the broad mass of humanity understands the urgent nature of the threat, and the political and moral imperative for drastic action to cut the number of warheads and fundamentally reassess strategic defence postures and doctrines.

This means we need to think as global citizens. On the initiative of Ban Ki-moon, we established the Ban Ki-moon Centre for Global Citizens here in Vienna in 2018. The Ban Ki-moon Centre works to empower women and young people to act as global citizens and to contribute to the accomplishment of the United Nations Sustainable Development Goals.

In this context, it is utmost necessary to mobilize young people to better understand and tackle the nuclear threat. Later today, the Ban Ki-moon Centre will co-host the Youth Forum on Global Citizenship and Youth Inclusion. In a lively session we will focus on the ways youth can contribute to the achievement of the United Nations Sustainable Development Goals as well as to peace and security. The forum will take place in this same hall, and I am looking forward to seeing many of you there, because I am convinced that the idealism of young people will be a powerful motivating force in the fight against nuclear weapons.

In 1998, Nelson Mandela, as President of the new, multiracial, democratic South Africa, addressed the United Nations General Assembly on the 60th anniversary of the Universal Declaration of Human Rights and posed a challenge to the leaders of the nuclear powers:

We must ask the question, which might sound naïve to those who have elaborated sophisticated arguments to justify their refusal to eliminate these terrible and terrifying weapons of mass destruction – why do they need them anyway? In reality, no rational answer can be advanced to explain what, in the end, is the consequence of Cold War inertia and an attachment to the use of the threat of brute force.

His words still ring true today. The time to act is now. Otherwise, we risk slipping from inertia into irreversible rigor mortis.

Thank you.

Federica Mogherini, (Italy) High Representative of the Union for Foreign Affairs and Security Policy and Vice-President of the European Commission (Video Message)

Dear Dr Zerbo,
Dear Friends,

I would have really loved to be in Vienna with you today.

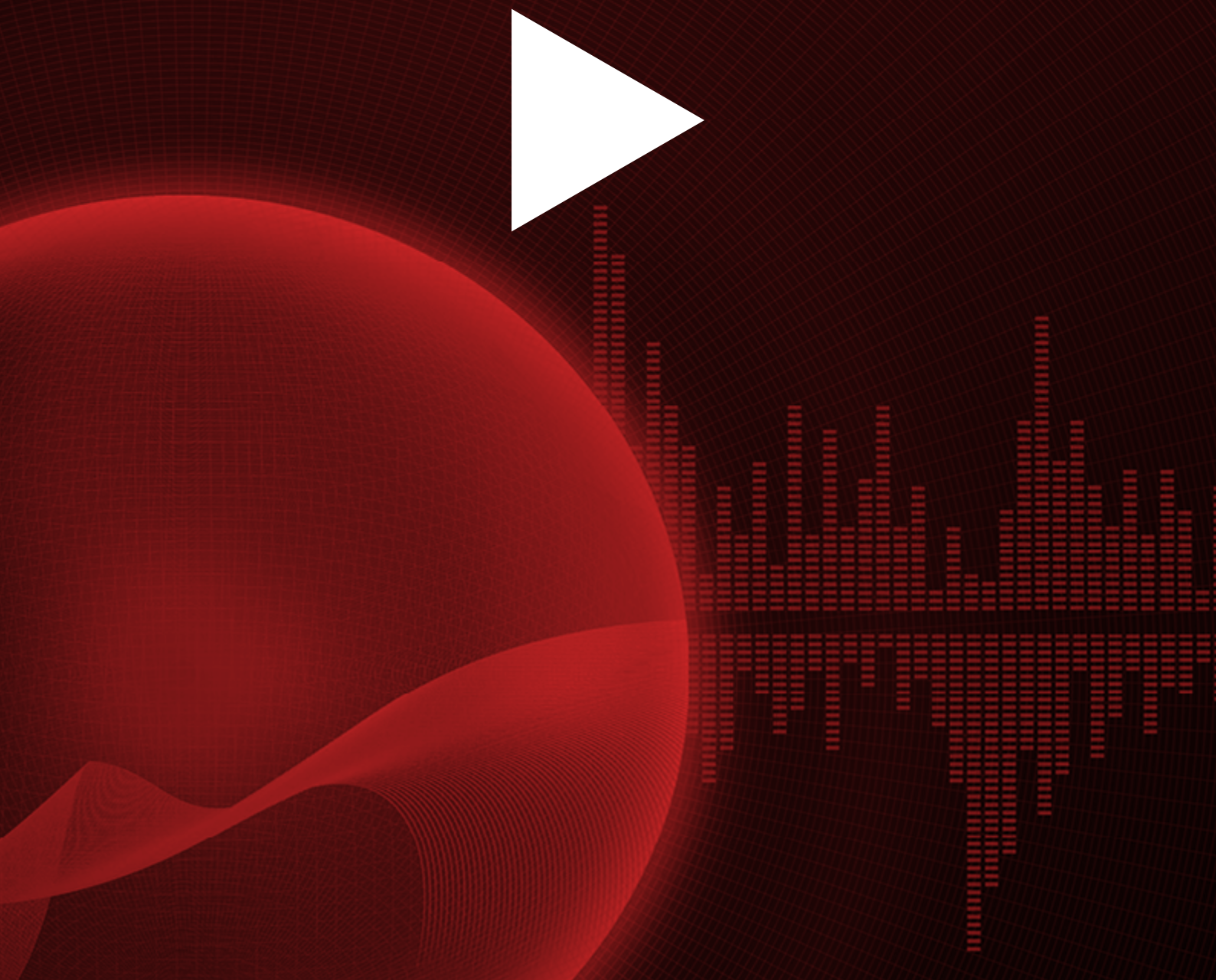
These are difficult times for the world. The pillars of our global non-proliferation architecture are being questioned. Instead of expanding the rules that guarantee us collective security, we see attempts to dismantle them. In times like this, we must do all in our power to preserve the existing rules, because only non-proliferation and disarmament can make our world more secure.

One of the best possible examples is the work of the Comprehensive Nuclear-Test-Ban Treaty Organization. The Treaty has provided the world with a truly global and high tech monitoring system for nuclear explosions, and this is something that no single country would be able to do alone. Our collective security can only be guaranteed through global architectures and multilateral agreements. When the Democratic People's Republic of Korea tested nuclear weapons, the International Monitoring System quickly provided independent and reliable data, which was essential for the international community to take strong and credible countermeasures. On top of that, cooperational nuclear issues have also brought substantial benefits in the civilian field. Data from the International Monitoring System is now used for early warning against natural disasters such as tsunamis and volcanic eruptions, but also to assess the impact of climate change. Such progress both on security as well as on civilian applications has only been possible thanks to cooperation with the global scientific community. Since the early days of the nuclear era, scientists have always been at the forefront of the work for non-proliferation, because scientists understand the dangers better than anyone else and we all need to hear the voice of science.

On our side, as the European Union we will continue not only to hear this voice, but also to support the Treaty and the organization, both politically and financially. We will continue to support the maintenance of monitoring stations at all corners of the world and to help you to track radioactive material in the atmosphere. Most importantly, we will continue to support the entry into force and universalization of the Treaty. In tough times like ours, giving up is a luxury that we cannot afford. It would be tempting to despair and simply wait for better times, but our first duty is to prevent the worst from happening and to prepare the ground for future progress. Better times will not come without our commitment, so I am truly grateful for all the work that you do and that we are doing together.

Thank you.

3. Oral and Poster Presentations



Oral and Poster Presentations

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 continues to be seismic and acoustic wave speed and attenuation, which are essential for locating seismoacoustic disturbances in the earth and its atmosphere and oceans. Another area is atmospheric dynamics relevant to the transport of radionuclides and the propagation of atmospheric infrasound. Yet another area is subsurface properties relevant to the detection of a nuclear explosion by geophysical, radionuclide or other methods during an on-site inspection. 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.

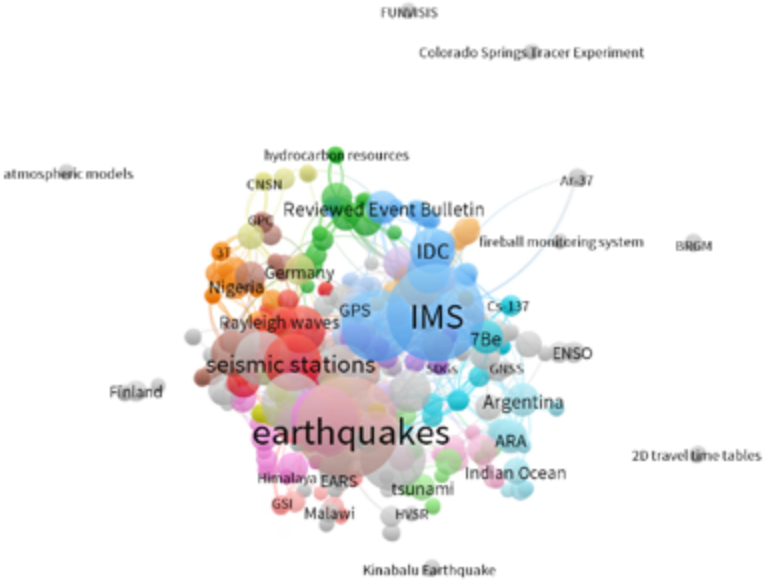


Figure 1. Theme 1 - Network visualization by keywords based on the Book of Abstracts (173 abstracts, 553 keywords, 36 clusters). CTBTO Library developed this figure using Mendeley and VOSviewer Software[1]

T1.1 Atmospheric Dynamics

The session demonstrated the growing and improving understanding of atmospheric variabilities within the atmospheric sciences and infrasound communities. For infrasound technology, atmospheric dynamics was covered with the presentation *Uncertainties in Numerical Weather Forecasting Models and Infrasound Simulations as Observed by the ARISE Project* (**T1.1-011)**, while for radionuclide technologies the topic was covered in *Probabilistic Predictions and Uncertainty Estimation Using Adaptively Designed Ensembles for Radiological Plume Modelling* (**T1.1-P23**). Such knowledge of the atmospheric variability appears to be deeply needed for expert analysis of events of interest and for analysing atmospheric trends.

[1] The size of the bubble corresponds to the number of abstracts that mention the specific keyword in the Book of Abstracts of SnT2019. The clusters are represented by colours. They are related to which keyword belongs in co-ocurrency. The bubbles in grey represent isolated keywords. Lines between bubbles represent connections between keywords. The distance between two bubbles indicates the relatedness of both in terms of frequency. The closer two keywords are located to each other, the stronger their relatedness.

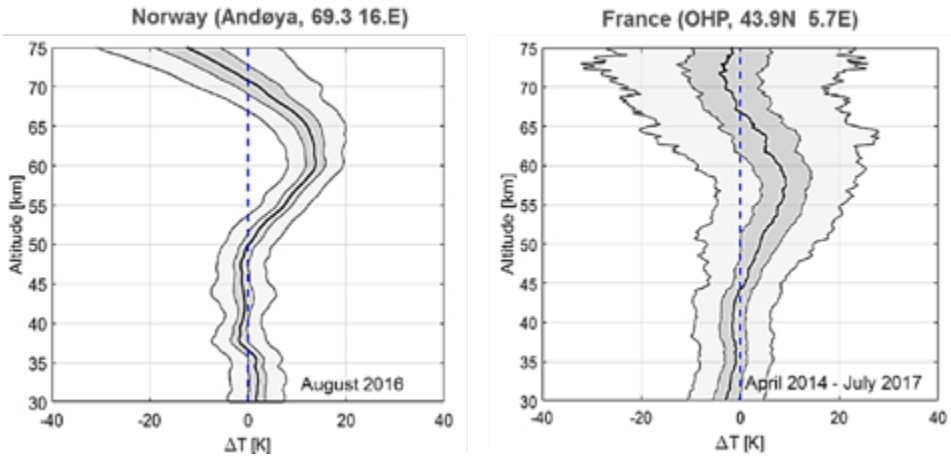


Figure 2. Model uncertainties related to atmospheric variability: Differences between lidar observations and ECMWF temperature profiles exceeds 10°K in the upper stratosphere and mesosphere. From E. Blanc et al. (T1.1-011).

There are high expectations regarding the assimilation of IMS data for both infrasound and radionuclide technologies, as presented in *Application of Advanced Data Assimilation Techniques to Improve Atmospheric Transport and Dispersion Predictions* (**T1.1-01**).

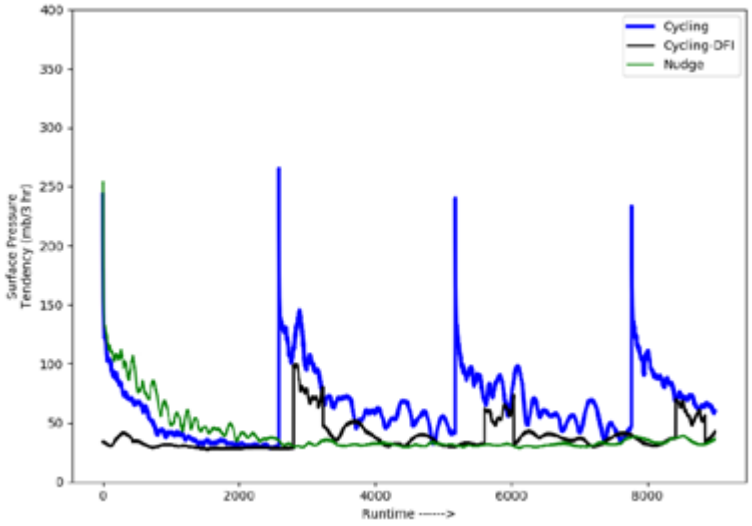


Figure 3. Surface pressure tendency: The case for nudging versus time cycles. Nudging allows for continuous assimilation over time and relaxes the modeled values toward observations. From N. Heath and A. Suarez-Mullins. (T1.1-01).

This appears to be of crucial importance for numerical weather prediction, as demonstrated in *Infrasound Monitoring for Global Climate Model Calibration: A Two-Way Collaboration* (**T1.1-P17**) and helps in understanding global circulation processes.

The synergy between varieties of observation techniques is key for a wide range of scientific applications. Among others, the presentation *Assessing Middle Atmosphere Weather Models Using Lidar and Ambient Noise* (**T1.1-02**) demonstrates the synergy between techniques. Synergies between different domains also support the advancement of research on near earth object monitoring, which was the focus of a panel discussion and several presentations, such as *Detection Efficiency of the IMS for Bolides* (**T1.1-05**), and on gravity wave characterization, as discussed in *Recording of Internal Gravity Waves and Infrasound Waves from the Warm and Cold Fronts in Moscow Region* (**T1.1-07**).

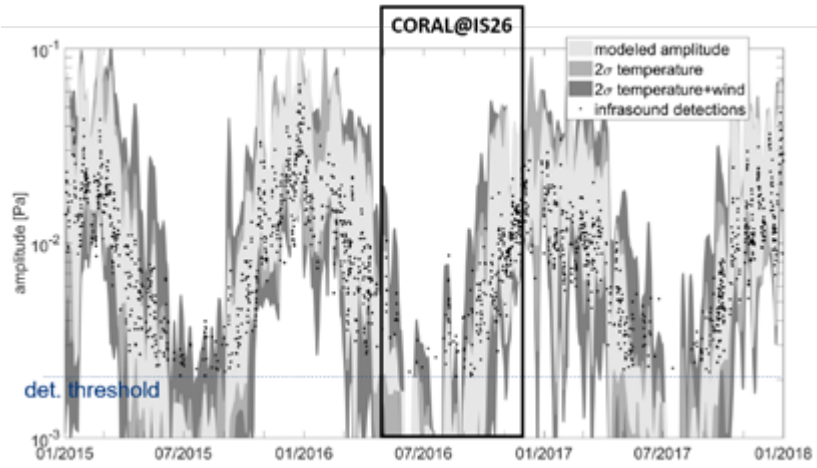


Figure 4. Modeling the amplitude and uncertainties of ocean swell (based on ECMWF, CORAL measurements and RMR lidar) and comparison with infrasound detections at IS26 (Germany). From P. Hupe et al, (T1.1-02). Adapted from: P. Hupe et al, Assessing middle atmosphere weather models using infrasound detections from microbaroms. Geophysical Journal International 216(3), 1761-1767, (2019). DOI:10.1093/gji/g.

Civil applications are becoming more prominent, ranging from research activities with ^{7}Be as presented in *Climate Change through the Eyes of Radioisotopes* (**T1.1-04**) to implementation in established operational systems for volcanic eruption monitoring as presented in *Look-Up Tables with Empirical Climatologies for Infrasound Detection, Location, and Characterization of Long Range Volcanic Eruptions* (**T1.1-P21**).

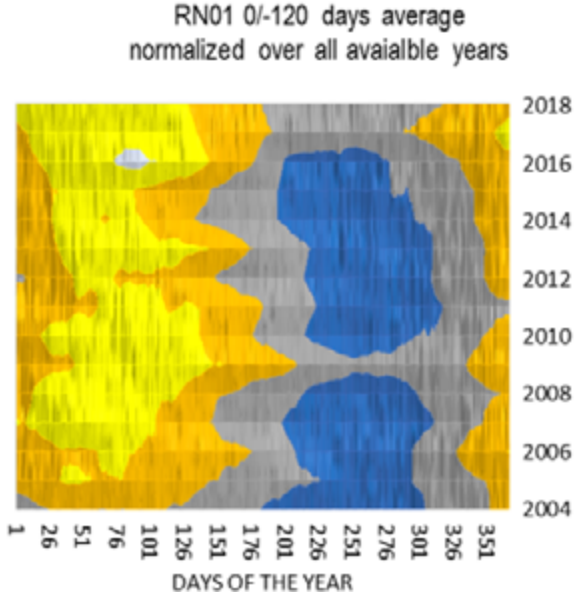


Figure 5. ^{7}Be a proxy for tropopause height variation, example for RN01 (Argentina) with cone shape Hectopascal demonstrating the longer the warm air, the higher the tropopause, the more extended is the period of ^{7}Be growth. From L. Terzi et al. (T1.1-04).

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

***T1.1-01** "Application of Advanced Data Assimilation Techniques to Improve Atmospheric Transport and Dispersion Predictions" provides guidance for the meteorological community as to which data assimilation techniques provide the most value for transport and dispersion simulations.

***T1.1-02** "Assessing Middle Atmosphere Weather Models Using Lidar and Ambient Noise: A Case Study for IS26" concludes that using high resolution light detection and ranging (lidar) at IMS infrasound stations can improve the understanding of infrasound observation.

T1.1-03 "Atmospheric Boundary Layer as a Laboratory for Modeling Infrasound Propagation and Scattering in the Atmosphere" presents an experimental study of the propagation of acoustic pulses from artificial detonation sources in a stably stratified atmospheric boundary layer.

***T1.1-04** "Climate Change Through the Eyes of Radioisotopes" shows how cosmogenic radionuclides detected by the IMS network can confirm climate change phenomena from a different perspective.

***T1.1-05** "Detection Efficiency of the IMS for Bolides" examines the efficiency of the IMS to detect airbursts by season, airburst energy and other variables.

T1.1-06 "NEMO - A Global Near Real-Time Fireball Monitoring System" introduces a project to develop a worldwide and near real time monitoring system for bright fireballs using multiple observation networks and complementary sources of information.

***T1.1-07** "Recording of Internal Gravity Waves and Infrasound Waves from the Warm and Cold Fronts in Moscow Region" presents the temporal changes in the characteristics of internal gravity waves and infrasonic waves with the passage of warm and cold fronts through the regional infrasound stations.

T1.1-08 "Remote Monitoring Volcanic Eruptions Using IMS Infrasound Data" shows how IMS infrasound data are being used by civil protection authorities to remotely monitor volcanic eruptions.

T1.1-09 "Temperature and Wind Atmospheric Lidars as Tools for the Validation of Infrasound Propagation Models" argues that the collocation of lidar and microbarometer arrays is an ideal way to test infrasonic propagation models because the propagation of infrasound waves depends on the wind and temperature vertical profiles provided by lidar.

T1.1-010 "The Effect of Atmospheric Boundary Layer on the Detected Radionuclides in Kuwait" provides an assessment of the atmospheric behaviour from the ground to 1000 m using upper air data along with data collected from IMS radionuclide station RN40.

***T1.1-011** "Uncertainties in Numerical Weather Forecasting Models and Infrasound Simulations as Observed by the ARISE Project" presents how the Atmospheric dynamics Research InfraStructure in Europe (ARISE) project provides new data sets for assimilation in medium range weather prediction models and in operational infrasound simulations to mitigate significant regional uncertainty differences.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T1.1-P2 "Analysis of Multiple Detections of May 2011 Grímsvötn (Iceland) Eruptive Activity at Different IMS Infrasound Stations and Its Correlation with Local Observations" presents long range observations of the May 2011 Grímsvötn eruptive activity recorded by the IMS infrasound network and relates the volcanic sources of the infrasonic waves to events listed in the Reviewed Event Bulletin of the IDC.

T1.1-P3 "Analysis of Multiple Detections of Mount Etna Eruptive Activity at Different IMS Infrasound Stations Compared with Near Source Observations" uses IMS infrasound stations as a tool to monitor near- and far-field volcanic activity, in particular the activity of Mount Etna.

T1.1-P5 "ARISE Project: Infrasound Monitoring for Civil Applications" presents civil applications of the Atmospheric dynamics Research InfraStructure in Europe (ARISE) project, which combines the infrasound network of the CTBTO with lidar and radar networks and satellites for an improved description of atmospheric dynamics.

T1.1-P6 "Assessing Middle Atmosphere Weather Models Using Lidar and Ambient Noise: A Case Study for IS02" provides first results of collocated lidar and infrasound measurements covering a time period of more than a year and highlights the seasonal differences in infrasound data with enhanced accuracy.

T1.1-P8 "Characterizing Ocean Ambient Noise Using Infrasound Network" explores middle atmosphere dynamics and disturbances by characterizing infrasound ambient noise.

T1.1-P10 "CORAL – An Autonomous Middle Atmosphere Lidar in Southern Argentina" discusses mobile wind lidar technology and presents the mobile Compact Rayleigh Autonomous Lidar (CORAL), a prototype that can improve the understanding of infrasound observations.

T1.1-P11 "Estimating Tropospheric and Stratospheric Large-Scale Wind Components Using Infrasound from Explosions" demonstrates that an average large scale crosswind can be estimated solely from infrasound data and suggests using this approach for estimating the tropospheric and stratospheric large scale wind components.

T1.1-P14 "IDC Infrasound Technology Developments" presents a number of ongoing projects at the IDC, such as detection accuracy improvement, development of NET-VISA software and a path for revisiting the historical IDC Infrasound Reference Event Database (IRED).

T1.1-P15 "Improving Propagation-Based, Stochastic Models for Bayesian Infrasonic Localization and Characterization" presents an overview of the construction and use of propagation models using atmospheric updating techniques and Bayesian methodologies and discusses several applications.

T1.1-P16 "Improving the Infrasound Monitoring Capability in Europe Incorporating CEEIN" discusses the recently installed Central and Eastern European Infrasound Network (CEEIN) and how it has significantly improved the monitoring capability of the European infrasound network.

***T1.1-P17** "Infrasound Monitoring for Global Climate Model Calibration: A Two-Way Collaboration" shows how IMS infrasound detections can be used to improve both global climate predictions and IDC network processing using artificial intelligence.

T1.1-P18 "Infrasound Propagation in Multiple-Scale Random Media Using Surrogate Models" shows how probabilistic surrogate models obtained using a few realizations of the atmosphere can be used for real time processing, thus mitigating the problem of computational cost that prohibits the use of important aspects of wave propagation in IDC processing.

T1.1-P19 "Large Events Recorded at the IMS Infrasound Network" provides examples of events in the Reviewed Event Bulletin that were recorded at many stations of the IMS infrasound network.

T1.1-P21 "Look-Up Tables with Empirical Climatologies for Infrasound Detection, Location, and Characterization of Long Range Volcanic Eruptions" proposes a robust and fast way to calculate where infrasound signals in IMS stations come from and shows that it is possible to implement this method to detect, locate and characterize volcanic eruptions.

T1.1-P22 "On the Use of Infrasound Observations from Volcanoes for Improving the Weather Forecasts" introduces a maximum likelihood approach for selecting atmospheric data within ensembles of short range forecasts and analyses to objectively estimate the atmospheric specification required in infrasound applications.

***T1.1-P23** "Probabilistic Predictions and Uncertainty Estimation Using Adaptively Designed Ensembles for Radiological Plume Modelling" highlights novel approaches using machine learning and initiates discussions about ways to incorporate meteorological uncertainty into IDC analysis and products.

T1.1-P25 "Temporal Variations of the Intensity Spectra of Atmospheric Pressure Fluctuations in Different Frequency Ranges and Their Possible Connection with Climate Change" investigates the capabilities of the IMS network for studying climate change and the impact of dynamic processes in the atmosphere on human health.

T1.1-P26 "The Global and Coherent Infrasound Field: Revisiting the Reprocessing of the Full International Monitoring System Infrasound Data, Part 1: Processing" presents the results of global coherent infrasound measured at IMS infrasound stations and its correlation with atmospheric dynamics.

T1.1-P27 "The Global and Coherent Infrasound Field: Revisiting the Reprocessing of the Full International Monitoring System Infrasound Data, Part 2: Examples" revisits the reprocessing of the infrasound data set that paved the way for gaining new insight into infrasonic atmospheric wave phenomena such as mountain-associated waves.

T1.1-P28 "The Influence of Tropospheric Ducts on Long Range Infrasound Propagation" discusses the influence of the troposphere, which is often overlooked in operational models of infrasound propagation and detection, even though it can be significant.

T1.2 Solid Earth Structure

Highlights

Presentation *3-D Seismic Velocity Model of the Eastern Mediterranean Region Using Body-Wave Tomography* given (**T1.2-01)** focused on the development of a high resolution body wave velocity model of the Eastern Mediterranean. The seismic velocity model is one of the factors that influence the accurate location of events the most. The location of an event is also very important in being able to differentiate between natural earthquakes and man-made seismic disturbances. The regional seismic travel time framework, which provides one degree spatial resolution, is too coarse for studies in Israel. Local tomographic studies and ground truth events may in future enhance the ability of the CTBTO to detect and locate events in the region.

Presentation *Earthquake Swarms and Reactivation of Seismicity Associated with the 2015 Mw 7.8 Gorkha Earthquake in Nepal* (**T1.2-02**) described the continuous monitoring of seismicity of the Central Himalayas by the 21 seismic stations of the national seismic network of Nepal. Auxiliary seismic station AS68 was discontinued because it is too difficult to maintain at its current location.

Presentation *Estimation of Local Seismic Activity by Deterministic Hazard Assessment: A Case Study in North-Eastern of Azerbaijan* (**T1.2-03**) focused on seismic hazard assessment, using a deterministic approach, of the southern slope of the Greater Caucasus.

Presentation Revised Local- and Regional-Scale Velocity and Attenuation Models for Canada for Improved Earthquake/Explosion Location, Magnitude and Yield Estimates (T1.2-04) reviewed significant advances made in the regional seismic travel time model in Canada using natural and mining related seismic events.

The starting model, rstt201404um, was used, and wave speeds were optimized to minimize time residuals. Moreover, a 50% reduction in travel time residuals for Lg arrivals was achieved and 17% or better was achieved for Pg, Pn and Sn.

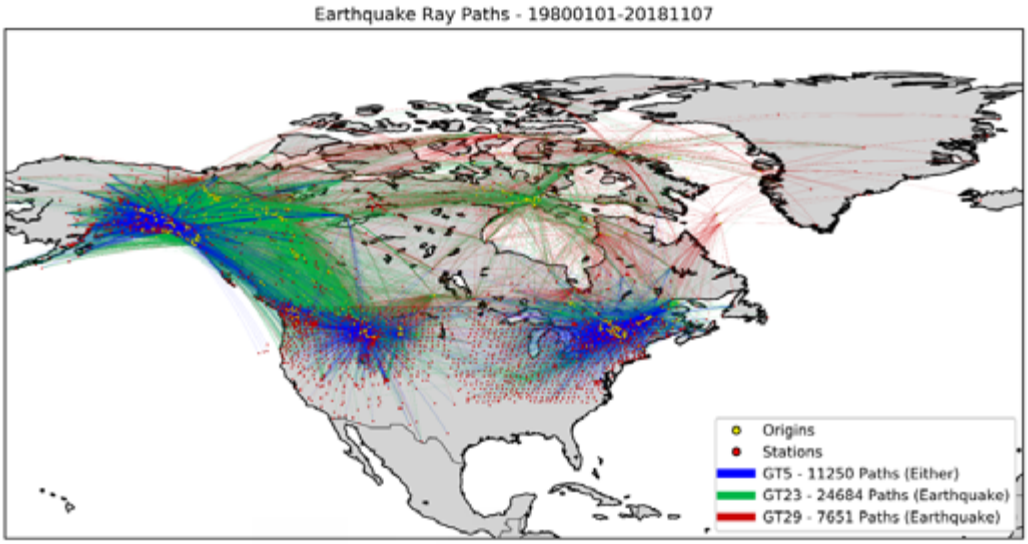


Figure 6. Extension of the Regional Seismic Travel Time North American model into Canada using National Earthquake DataBase (NEDB) travel time dataset as input into Regional Seismic Travel Time model, map of natural earthquakes. From C. Perry. et al. (T1.2-04).

Presentation *Updates to the Regional Seismic Travel Time (RSTT) Tomography Model* (**T1.2-06**) reviewed advancements in the regional seismic travel time model since 2014. A new data set was developed using Bayesloc (joint relative location). Regional seismic travel time code modification has started to include 2-D uncertainty. The goal is to be able to estimate a path-dependent travel time uncertainty as part of the location determination built into the software package. For instance, this could be included in the National Data Centre (NDC) in a box software package. Future work to assist in creating source specific station corrections for all regional phases is foreseen. This activity also involved outreach workshops.

Overview of Oral Presentations

T1.2-01 "3-D Seismic Velocity Model of the Eastern Mediterranean Region Using Body-Wave Tomography" presents the development of a high resolution seismic velocity model for the Eastern Mediterranean region in order to accurately locate and characterize events.

***T1.2-02** "Earthquake Swarms and Reactivation of Seismicity Associated with the 2015 Mw 7.8 Gorkha Earthquake in Nepal" studies the seismicity around the Main Himalayan Thrust fault, which even today is five times higher than the background seismicity before the Gorkha earthquake in 2015.

***T1.2-03** "Estimation of Local Seismic Activity by Deterministic Hazard Assessment. A Case Study in North-Eastern of Azerbaijan" presents a large scale seismicity analysis for seismic zone clarification and maximum earthquake magnitude estimation.

***T1.2-04** "Revised Local- and Regional-Scale Velocity and Attenuation Models for Canada for Improved Earthquake/Explosion Location, Magnitude and Yield Estimates" presents new seismic velocity and attenuation models for Canada that will help the monitoring community reduce earthquake/explosion location errors and regional magnitude bias and improve explosive yield estimates.

***T1.2-06** "Updates to the Regional Seismic Travel Time (RSTT) Tomography Model" presents updates in the regional seismic travel time model to improve coverage and accuracy and include path-dependent uncertainty estimates for all regional phases.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T1.2-P1 "22 New Focal Mechanism Solutions for Shallow Earthquakes and Stress Observations for Bolivia (Plurinational State of)" presents new focal mechanism solutions for any region in the world to help decision makers reduce natural hazards.

T1.2-P9 "An Improved Velocity Model for Routine Hypocentre Location in Central Brazil" proposes a new 1-D velocity model with station delays specifically calculated for central Brazil that could replace the generic model based on previous limited data sets that is currently used.

T1.2-P12 "Analysis of Unusual Seismic Events in Northwestern Madagascar" interprets an unusual seismic event of magnitude 5.9 detected in the north-west of Madagascar and the thousands of earthquakes that followed as having originated from a magma shift under the seabed.

T1.2-P13 "Are We Able to Detect Viscoelastic Inconsistencies in the Earth?" suggests that the search for the viscoelastic inconsistencies within the earth could be a new opportunity for the large and high quality corpus of IMS seismic records to contribute once again to the development of science and technology.

T1.2-P26 "Database from a Seismic Network to Monitor the 2018 Enhanced Geothermal System Stimulation in Espoo/Helsinki, Finland" presents a database with a data set collected during stimulation at a record-setting depth in hard rock, which offers multiple possibilities to study shallow earth structure and to compare and develop methods for the monitoring of shallow seismic events.

T1.2-P30 "Dissecting Hearts of the Continent in Southern Africa Using First P-Wave Tomography Based on Local, Regional, and Mining-Induced Earthquakes" provides an example of the application of IMS seismic data resources for geotomographic investigations.

T1.2-P37 "Flow Plane Orientation in the Upper Mantle Under the United States from SKS Shear-Wave Splitting Observations" shows that SKS shear wave splitting allows scientists to distinguish whether seismic anisotropy is due to fossil deformation or asthenospheric flow.

T1.2-P43 "Heterogeneities of Short-Period S Wave Attenuation Field in the Earth's Crust and Uppermost Mantle of the Eastern Tien Shan" describes the attenuation of S-waves in the lithosphere of the Eastern Tien Shan including the Lop Nor nuclear weapons test site in China.

T1.2-P51 "Jordan Seismological Networks" explains how international networks of seismological stations will improve our knowledge of the earth's structure as well as the assessment of seismic hazards in seismic risk regions.

T1.2-P53 "Lithospheric Scattering and Structure from Teleseismic P waveforms" combines an energy flux model with analysis of the incoherent coda wavefield to determine heterogeneity in arrays located in different geological provinces.

T1.2-P58 "Monitoring of Crustal Activities Using Ocean Floor Network System for Disaster Resilience" introduces monitoring for earthquakes and tsunamis using an ocean floor network system.

T1.2-P63 "Prediction of Earthquake Hazard in the Northeast India Himalaya" uses earthquakes with magnitude Ms ≥5.5 from 1906 to 2008 in 19 delineated seismogenic sources in the Northeast India Himalaya to predict future earthquake hazards and finds that the probability of the occurrence of moderate to large size earthquakes in some of the seismogenic sources of Northeast India and its adjoining Southeast Tibet is significantly high, ranging from 0.81 to 1.0 for the next decade.

T1.2-P68 "Present-Day Stress Field in NW Himalaya and Surrounding Regions Based on Inversion of Earthquake Focal Mechanisms" performs stress field inversion in the north-west Himalaya and surrounding regions based on 584 earthquake focal mechanisms listed in the data bulletin of the International Seismological Centre.

T1.2-P71 "Properties of the High-Frequency Ambient Seismic Field Recorded on a Large-N (N=10,530) Seismic Deployment in the Vienna Basin" extends the approach of earth imaging based on ambient seismic noise techniques to higher frequencies and thus finer scale structures than commonly imaged.

T1.2-P73 "Recent Seismicity Along the Davie Ridge/Fracture Zone" addresses the issue of using seismic data from different agencies, e.g. the Kenya National Seismological Network, the CTBTO, the International Seismological Centre, the National Earthquake Information Center, the German Research Centre for Geosciences, to study the characteristics and dynamics of the Davie Ridge on the eastern coast of Africa.

T1.2-P80 "Seismic Hazard Scenario in Western Himalaya, India" uses seismicity data from 1963 to 2017 with Mw ≥4.0 in the region bounded by 29°N - 33°N latitude and 75°E - 81°E longitude, one of the most seismically active regions of Western Himalaya, and an appropriate attenuation model to compute the peak horizontal accelerations, peak vertical accelerations and ratios of peak vertical to horizontal accelerations and finds that larger peak ground accelerations are present in the region where there is a higher density of large faults and vice versa.

T1.2-P88 "Seismicity of the Okavango Delta Region: Contribution of IMS and Local Stations" makes the case that the techniques used for test ban verification can be very useful for scientific purposes in areas where scientific observatory infrastructures are either non-existent or limited.

T1.2-P95 "Sinkhole Process Interpretation Based on Shear Wave Seismic Reflection Results at Ghor Al-Haditha, Dead Sea" presents a shear wave reflection seismic study at the most destructive sinkhole site in Jordan, close to the village of Ghor Al-Haditha, and concludes that sequences of unconsolidated alluvial fan deposits dominate all of the seismic depth sections, starting from the top soil used for farming to a depth of at least 200 m.

T1.2-P102 "Stress/Strain State Colouring Method for IMS Data Imaging" recommends a user friendly approach to work with CTBTO data to facilitate imaging.

T1.2-P107 "Tectonic Plates Interactions and Detection Capabilities of the IMS Seismic Stations in the Africa Region" studies the interaction among the earth's subsystems in order to estimate the anticipated long term risk of intercontinental seismic events.

T1.2-P110 "The Caucasus Seismic Hazard" presents a project that aims to compile a regional seismic catalogue in order to provide reliable input for the seismic hazard assessment in the Caucasus, one of the most active segments of the Alpine-Himalayan system.

T1.2-P118 "Updating the Egyptian Earthquake Source Parameters Database" presents a new database for updated earthquake focal mechanism and source parameters for Egypt that comprises quality weighted focal mechanism solutions and different source parameters including seismic moment, fault radius, corner frequency, stress drop and moment magnitude.

T1.2-P119 "Upper Crustal Structure at the KTB Drilling Site from Ambient Noise Tomography" uses seismic ambient noise, mainly generated by interaction of oceanic swells, to image the subsurface structure at the German Continental Deep Drilling Program (KTB) site.

T1.2-P120 "Upper Mantle Imaging with Surface Wave Diffraction: AlpArray Seismic Network and the Cameroon Volcanic Line" uses stations in Europe to detect, locate and describe the anomalous arrival angles of seismic waves under the Cameroon Volcanic Line in central Africa and explain them as interference effects.

T1.2-P123 "Velocity of Seismic Waves in the Earth's Crust and Upper Mantle of the Siberian Platform and Baikal Folded Region According to Underground Nuclear Explosions" uses digitized historical records of underground nuclear explosions (UNEs) to determine the velocity structure of the Baikal Rift Zone and surroundings.

T1.2-P124 "SALSA3D Software Tools for Model Interrogation, Event Location and Travel-Time" presents software tools to develop velocity models and to improve the location and uncertainty of detected events.

T1.3 Properties of the Ocean

Highlights

The value of the IMS hydroacoustic network for detecting small impulsive sources was reaffirmed with the analysis of IMS data relating to the loss of the Argentine submarine *ARA San Juan*, as discussed in *Analysis of Hydroacoustic Signals Associated to the Loss of the Argentinian* ARA San Juan *Submarine* (**T1.3-01**), *CTBTO's Contribution to the Search of the Missing Argentine Submarine* ARA San Juan (**T1.3-03**), *Reducing Ambiguity in Hydroacoustic Triangulation Through Consideration of Three-Dimensional Propagation Features* (**T1.3-09**) and *Long-Range Ocean Sound Propagation Effects Related to the Search for the Argentine Submarine* ARA San Juan (**T1.3-P4**).

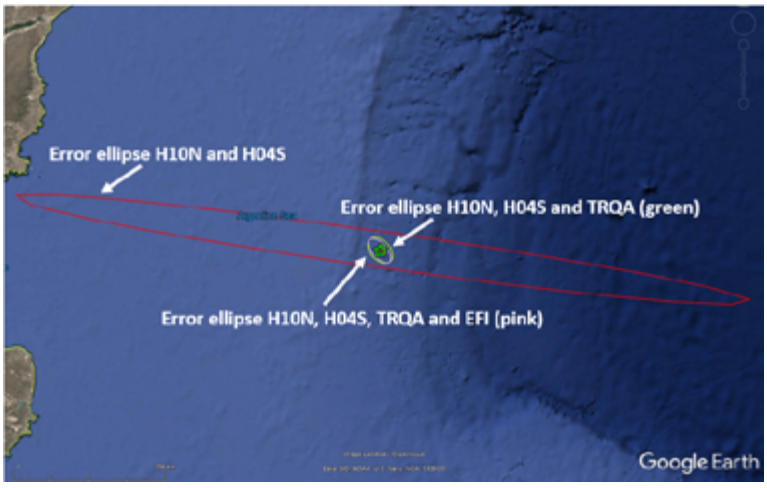


Figure 7. Estimate of location (stars) and associated uncertainty (error ellipses) of the unusual impulsive-like signal recorded by the CTBT IMS triplets H10N and H04S on 15 November 2017. From P.L. Nielsen et al. (T1.3-03).

Three independent analyses came to effectively the same conclusions. These results highlight one use of IMS data for civil and humanitarian purposes.

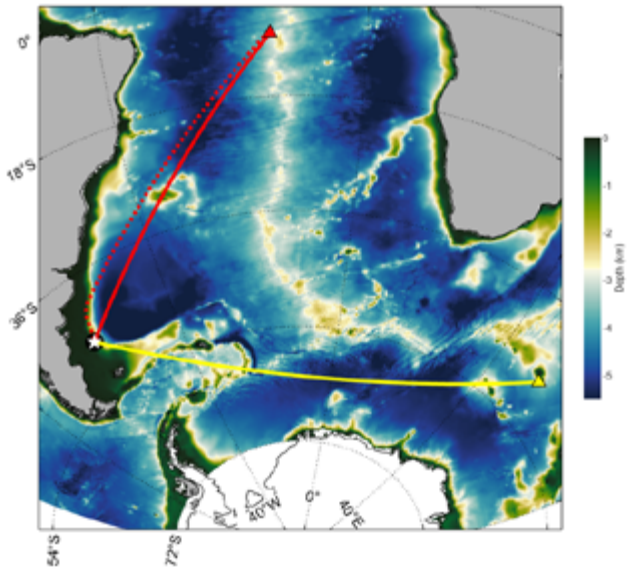


Figure 8. Three dimensional underwater acoustic propagation modelling to predict arrival times for a signal propagating along geodesic and horizontally refracted paths from the unusual event detected by the CTBT IMS hydrophone stations HA10 and HA04 on 15 November 2017 to the CTBT IMS hydrophone triplet H10N (red solid line) and hydrophone triplet H04S (yellow solid line). From D. Dall'Osto. (T1.3-09).

IMS hydroacoustic data also contribute to achieving the United Nations Sustainable Development Goals (SDGs), for example ocean soundscapes, marine mammal tracking, climate change, tsunami detection and underwater volcano monitoring, as presented in *Hydroacoustic Signatures 'Petition' for Social Change: Curating Hydroacoustic Data to Strengthen the Implementation of Environmental Dimensions of the SDGs* (**T1.3-04**), *Distributed Detection Framework and Three-Dimensional Propagation Model for Acoustic Detection of Baleen Whales* (**T1.3-05**), *Scenario-Based Tsunami Hazard Assessment for Karpathos Island, Southeastern Aegean Sea* (**T1.3-P5**) and *Suprapodal Hydroacoustic Observations of Earthquakes along the Middle America Trench* (**T1.3-P8**).

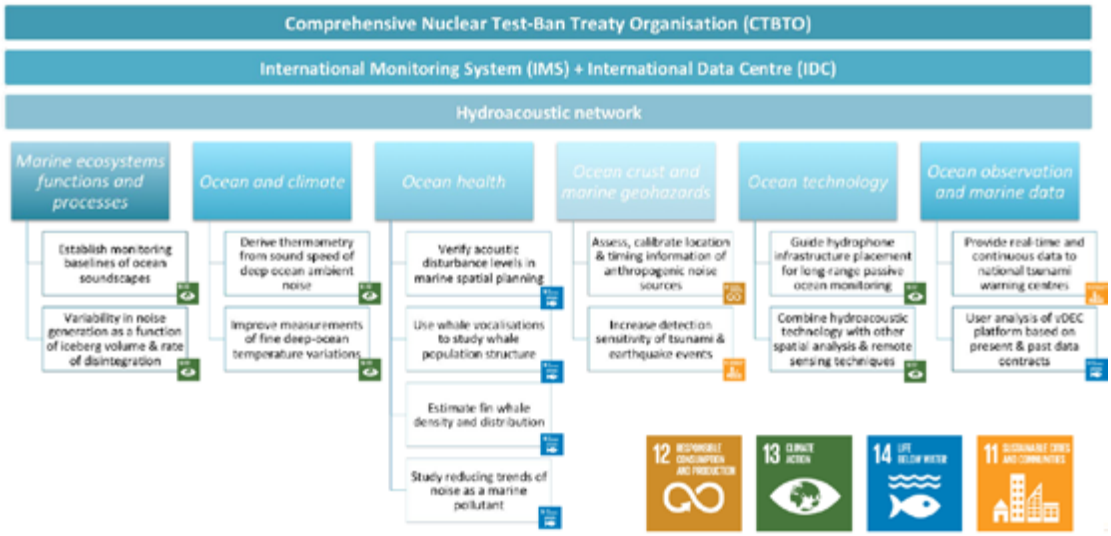


Figure 9. Connection between the CTBT IMS hydroacoustic network and the United Nations Sustainable Development Goals. From K.C.J. Ho. (T1.3-04).

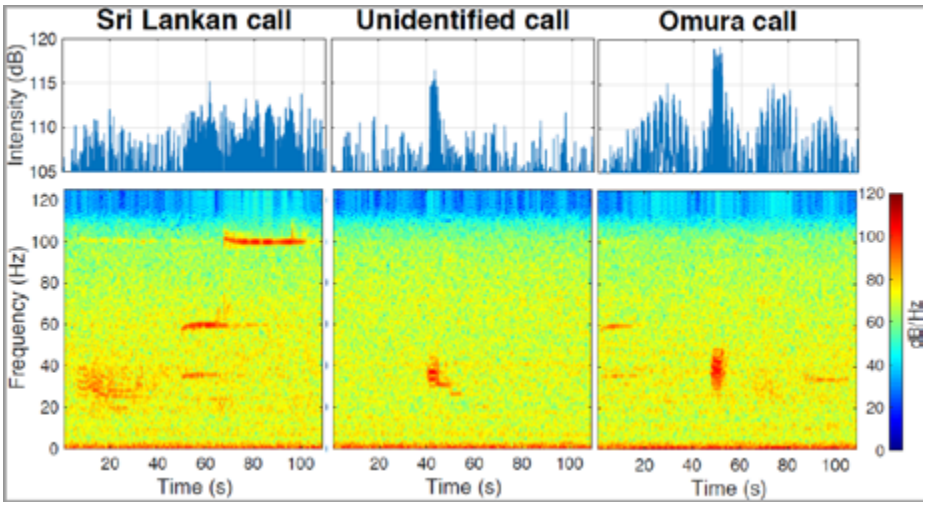


Figure 10. Spectrograms from the CTBT IMS hydroacoustic station recordings at Diego Garcia in the Indian Ocean of three types of marine mammal vocalizations. From N.R. Pinto and T.K. Chandrayadula. (T1.3-05).

Figure 11. Trunk cable shore landing at the CTBT IMS hydroacoustic station HA04 (Crozet Island) utilizing improved vessel positioning and control systems. From J. Cummins et al. (T1.3-06).

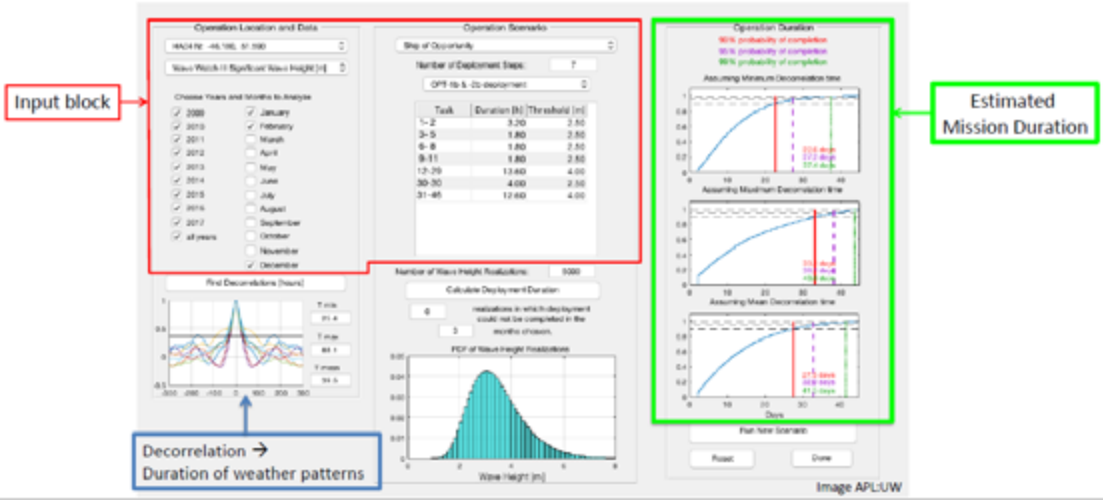


Figure 12. Monte Carlo Mission Time Simulator to support weather risk-based planning of maritime operations relevant to the CTBTO. From M. Zampolli et al. (T1.3-07).

Generally, presentations, including *Enabling Technology to Extend Life and Utility of Hydroacoustic Systems* (**T1.3-06**),*Monte Carlo Simulation Tool for Maritime Operations Risk Reduction and Enhancement of IMS Hydroacoustic Network Sustainment* (**T1.3-07**), *OOI Cabled Array Winched Profiler Data for Improved Hydroacoustic Analyses* (**T1.3-08**) and *Subspace Detection of Seismic Survey Signals Observed on the IMS Hydroacoustic Network* (**T1.3-P7**), highlighted the key ingredients to successful maritime operations, including robust engineering, understanding the environment, sustainment through modularity and planning using quantitative probabilistic risk reduction. These are in line with current CTBTO strategy.

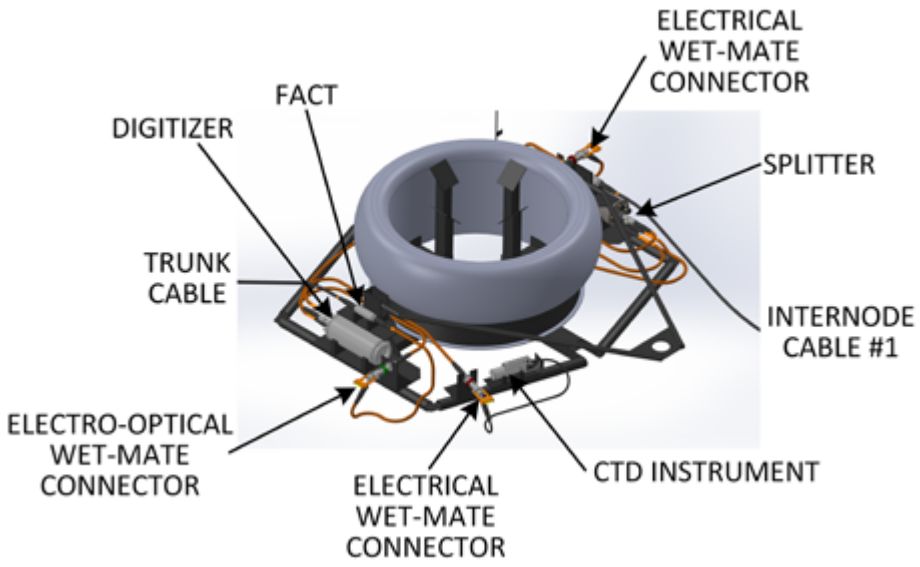


Figure 13. Schematic of proposed modular design nodes for next generation CTBT hydroacoustic systems in order to enhance sustainability (collaboration between University of Washington Applied Physics Laboratory and the PTS). From L. Zurk. et al. (T1.3-08).

One of the future goals identified was the need to better understand the conversion of ocean T phase energy to land based seismic energy in order to provide more reliable input for subsequent analysis and for incorporation into IDC processing, as discussed in *Calculation of Hydroacoustic Propagation and Conversion to Seismic Phases at T-Stations* (**T1.3-02**) and *IMS Discrimination Between T-Phases Originating from Volcanic Tremors Versus H-Phases Induced by Volcanic Eruptions in the Northwestern Pacific Ocean* (**T1.3-P3**).

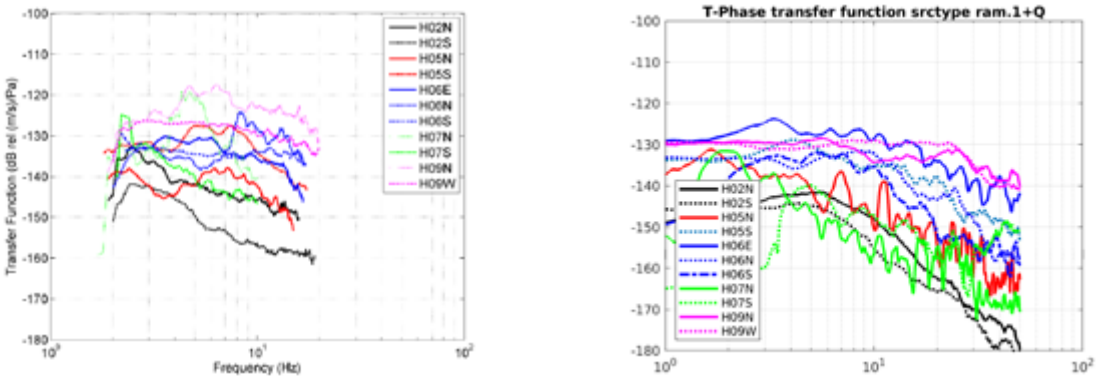


Figure 14. Observed (left) and calculated (right) seismic to hydrophone spectral amplitude conversions (smoothed) for all CTBT IMS T stations. From J. Stevens et al. (T1.3-02).

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

***T1.3-01** "Analysis of Hydroacoustic Signals Associated to the Loss of the Argentinian *ARA San Juan* Submarine" presents a method to locate the position of the submarine as well as waveform modelling and cepstral analysis to separate source and propagation effects.

***T1.3-02** "Calculation of Hydroacoustic Propagation and Conversion to Seismic Phases at T-Stations" performs numerical calculations to model the complex conversion of in-water signals to seismic signals on land, i.e. the signals captured by the IMS T phase stations.

***T1.3-03** "CTBTO's Contribution to the Search of the Missing Argentine Submarine *ARA San Juan*" presents the expert technical analysis by CTBTO staff leading to the initial estimate of the location of the acoustic anomaly recorded at IMS hydroacoustic stations HA4 and HA10 related to the search for the missing Argentine submarine *ARA San Juan*.

***T1.3-04** "Hydroacoustic Signatures 'Petition' for Social Change: Curating Hydroacoustic Data to Strengthen the Implementation of Environmental Dimensions of the SDGs" presents a project that investigates how hydroacoustic data can be utilized to assess the state of health of the oceans and provide key indicators for the sustainable use of their resources and explores critical linkages within and between environment related SDGs and the development of indicators to support their implementation.

***T1.3-05** "Distributed Detection Framework and Three-Dimensional Propagation Model for Acoustic Detection of Baleen Whales" uses IMS data to support acoustic models and develop signal processing methods in order to track whales.

***T1.3-06** "Enabling Technology to Extend Life and Utility of Hydroacoustic Systems" presents a solution to continuously improve nuclear test monitoring by improving the serviceability of the hydroacoustic system and incorporating expandability into its design.

***T1.3-07** "Monte Carlo Simulation Tool for Maritime Operations Risk Reduction and Enhancement of IMS Hydroacoustic Network Sustainment" exploits ocean environmental data for maritime operations forecasts and risk mitigation, which is particularly valuable for challenging hydroacoustic station installations and sustainability.

***T1.3-08** "OOI Cabled Array Winched Profiler Data for Improved Hydroacoustic Analyses" presents temperature and salinity profiles over five years of operation of three novel winched profilers of the Ocean Observatories Initiative (OOI) cabled array related to the large scale oceanography off the coast of Oregon and suggests that adding ancillary instrumentation to IMS hydrophone stations could allow similar insights related to ocean monitoring.

***T1.3-09** "Reducing Ambiguity in Hydroacoustic Triangulation Through Consideration of Three-Dimensional Propagation Features" shows how signal recordings of multipath arrivals from the same source improves the event localization and reduces the associated uncertainty.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

***T1.3-P3** "IMS Discrimination Between T-Phases Originating from Volcanic Tremors Versus H-Phases Induced by Volcanic Eruptions in the Northwestern Pacific Ocean" shows that the IMS hydrophone triplets can identify pressure fluctuations associated with undersea eruptions.

***T1.3-P4** "Long-Range Ocean Sound Propagation Effects Related to the Search for the Argentine Submarine *ARA San Juan*" analyses the impact of ocean waveguide propagation on impulsive-like signals and suggests that the inclusion of long range propagation effects may improve the classification of distant signals from underwater impulsive events.

***T1.3-P5** "Scenario-Based Tsunami Hazard Assessment for Karpathos Island, Southeastern Aegean Sea" evaluates the tsunami hazard for Karpathos Island and finds that the seismic source Eastern Hellenic Arc dominates and that the southern part of Karpathos is more exposed to tsunamis.

***T1.3-P7** "Subspace Detection of Seismic Survey Signals Observed on the IMS Hydroacoustic Network" presents a subspace detector with the capability to discriminate temporally collocated signals and discusses azimuth selectivity and performance improvement by mitigating the impact of marine air-gun seismic surveys.

***T1.3-P8** "Suprapodal Hydroacoustic Observations of Earthquakes along the Middle America Trench" shows that IMS instruments can pick up low frequency underwater sound waves over source–receiver ranges of more than 21 000 km.

T1.4 Interaction Among the Earth's Subsystems

Highlights

Poster *Be-7 in South America: Detection by IMS Radionuclide Stations and Possible Applications for Climate and Environmental Studies* (**T1.4-P1**) analysed the emission of ^{7}Be around the South Pole and the spatial and temporal variations of ^{7}Be concentrations detected by the IMS stations in Buenos Aires, Argentina; Montevideo, Uruguay; and Punta Arenas, Chile. If the results are consistent, the technique used could serve as a new civil application of CTBT technologies.

Poster *Modulation of Gas Fluxes at the Soil-Atmospheric Interface Due to Coupled Physical, Chemical and Biological Effects* (**T1.4-03**) described a study which discovered that gas flux has a different behaviour during the day and at night. If the results are consistent, this should be taken into account during OSI exercises and inspections.

Table 1. Magnitude of Seismic Surface Waves Versus Height for a 20 kT Explosion

[Height [km	Mb
10	3.0
1	3.5
surface	4.0
-0.3	5.0

From Paul W. Pomeroy, Long period seismic waves from large, near-surface nuclear explosions. Bulletin of the Seismological Society of America, 53(1):109-149, January 1963. Y. Ben Horin. (T1.4-01).

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

T1.4-01 "Atmospheric Events Energy Estimation Based on Seismic Data" shows how to more accurately estimate an event energy release, thus helping to characterize the event source.

T1.4-02 "Complex Propagation of Explosion-Generated Infrasound Revealed by the Large-Scale AlpArray Seismic Network" highlights the usefulness of dense seismic networks when studying the complex propagation of infrasound generated by explosions on a regional scale using data from 400 seismic stations following a refinery explosion near Ingolstadt, Germany, on 1 September 2018.

***T1.4-03** "Modulation of Gas Fluxes at the Soil-Atmosphere Interface Due to Coupled Physical, Chemical and Biological Effects" describes experimental and modelling capacities developed to tackle inaccuracies caused by variable water content and plant growth in soils that strongly modulate in space and time gas fluxes emitted at their surface.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

***T1.4-P1** "^{7}Be in South America: Detection by IMS Radionuclide Stations and Possible Applications for Climate and Environmental Studies" characterizes the spatial and temporal variability of ^{7}Be concentrations in South America by analysing IMS data to identify anomalous high ^{7}Be concentration events and traces the enriched ^{7}Be air masses back to their source.

T1.4-P9 "Monitoring Seismic Events and Content of Isotopes on Atmospheric Aerosol of Tajikistan" investigates various atmospheric phenomena and isotope distributions in the atmospheric aerosol samples from southern, central and northern Tajikistan prior to earthquakes.

T1.4-P10 "Observations of Interactions Among Earth's Subsystems from the EarthScope Transportable Array" presents examples of a multitude of signals recorded across the earth by the IMS and discusses the interactions between different parts of the earth as well as lessons learned from them.

T1.4-P13 "Seismo-Acoustic Observation of the Ocean Swell Sources at BURAR Site" investigates typical sources observed by both types of sensors of a four-element seismoacoustic array deployed at the Bucovina Seismic Array (BURAR) site in northern Romania.

T1.4-P15 "ThunderSeis: Seismic Analysis of Thunder Infrasound" analyses thunder signals from the AlpArray seismological network and compares them with the Austrian Lightning Detection and Information System (ALDIS) in order to understand the phenomenon and its impact on seismic and infrasonic recordings.

T1.4-P16 "Use of IMS Facilities for Monitoring Hazardous Geophysical Phenomena and Climate Change in the Antarctic Peninsula Region" demonstrates possible civil applications of monitoring methods, including in the circumpolar regions.

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. Factors to consider could include recognizing features that may indicate a decommissioned and decontaminated site or those that may suggest an active or reopened site. The types of expertise and capabilities required for these purposes need to be elaborated and could become relevant in the case of any contingency operations that would call upon CTBTO technological capabilities, if requested and if approved by the States Signatories.

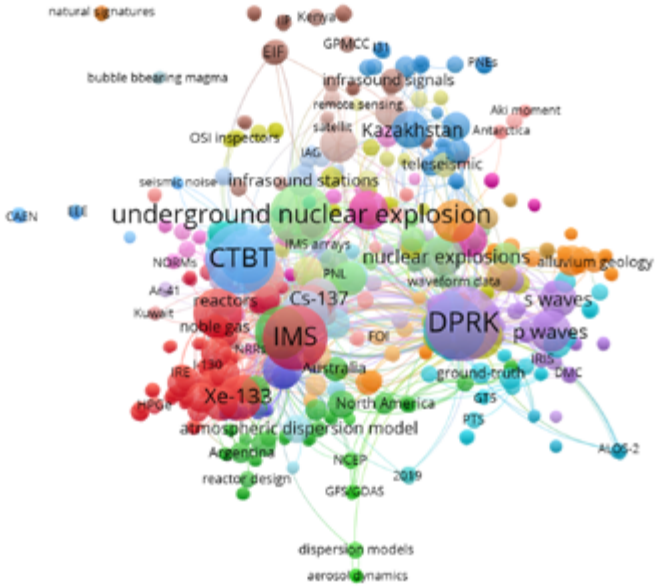


Figure 15. Theme 2. Network visualization by keywords based on the Book of Abstracts (166 abstracts, 643 keywords, 31 clusters). CTBTO Library developed this figure using Mendeley and VOSviewer Software[2].

T2.1 Characterization of Treaty-Relevant Events

Highlights

Presentation *Infrasound Records Associated with the Western of Yunnan Fireball on October 4, 2017* (**T2.1-01**) showed the value of combining local and IMS infrasound stations to observe smaller atmospheric explosions observed at a single IMS station. This highlights the role of the IMS network as a constant, reliable backbone to which permanent or temporary regional stations can be added.

Presentation *Physical Characterization of Filters from German and Sweden Radiological Monitoring Networks with Ru-106 from 2017* (**T2.1-02**) showed how more advanced methods of processing filters, including electron microscopy, autoradiography and coincident high resolution gamma spectrography, could be used at IMS radionuclide particulate stations to enhance the scope and accuracy of the stations.

[2] The size of the bubble corresponds to the number of abstracts that mention the specific keyword in the Book of Abstracts of SnT2019.
The clusters are represented by colours. They are related to which keyword belongs in co-ocurrency. The bubbles in grey represent isolated keywords. Lines between bubbles represent connections between keywords. The distance between two bubbles indicates the relatedness of both in terms of frequency. The closer two keywords are located to each other, the stronger their relatedness.

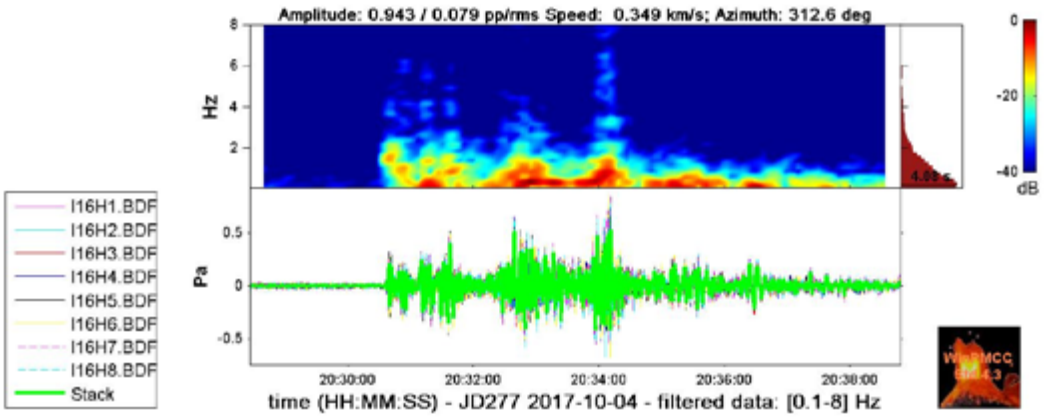


Figure 16. Data analysis of the Western of Yunnan Fireball on 4 October 2017 recorded by IS16 Infrasound Arrays located at about 450 km from the hypothesized source region. From W. Su. (T2.1-01).

Several presentations, including *Seismic Full Moment Tensor Analysis of Nuclear Explosions in North Korea* (**T2.1-04**) and *The 2017 North Korean Nuclear Test - A Comprehensive Multi-Technology Analysis* (**T2.1-06**), focused on using the moment tensor technique in relation to the tests by the Democratic People's Republic of Korea and related events, such as the collapse event eight minutes after the sixth test. This technique and ways to display the results have now reached a mature level and could be used routinely in IDC processing. Presentation **T2.1-06** also demonstrated multi-technology comprehensive analysis combining IDC techniques and additional National Technical Means.

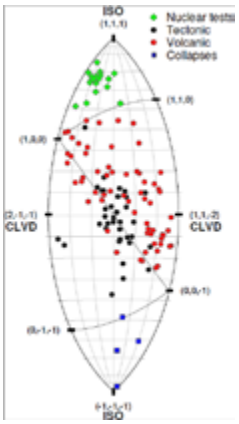


Figure 17. Full moment tensor catalogs for nuclear tests, tectonic events, volcanic eruptions and collapses, plotted on the lune. From C. Alvizuri and C. Tape. (T2.1-04).

Presentation *Possibilities to Identify Cavity Due to UNE Using Seismic Wave Fields* **(T2.1-03)** described the role of numerical modelling in understanding the seismic wavefield changes caused by the presence of a cavity and rubble zone resulting from an underground nuclear explosion.

The use of detailed analysis of surface reflections in seismic data to understand the depth of the underground events was illustrated in the presentation *Seismic Spectral Ratios Between North Korean Nuclear Tests: Implications for Their Seismic Sources* (**T2.1-05**).

Presentation *UK NDC Analysis of IMS Radionuclide Events Near to North Korea* (**T2.1-07**) described the radionuclide and atmospheric transport modelling (ATM) processing pipeline at the National Data Centre of the United Kingdom to illustrate the complexity of pinpointing the source of ^{133}Xe in the absence of other relevant detected isotopes.

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

***T2.1-01** "Infrasound Records Associated with the Western of Yunnan Fireball on October 4, 2017" uses the progressive multichannel cross-correlation (PMCC) method to estimate wave parameters at infrasonic arrays and the source location of the Yunnan fireball of October 2017.

***T2.1-02** "Physical Characterization of Filters from German and Sweden Radiological Monitoring Networks with Ru-106 from 2017" investigates important verification questions raised by the widespread observation of unusual Treaty-relevant radionuclides, such as what the observed radionuclides mean in terms of CTBT verification and whether the current available technical policies and tools allow for a full understanding of such events.

***T2.1-03** "Possibilities to Identify Cavity Due to UNE Using Seismic Wave Fields" explores the question of whether it make sense to deploy seismometers at the site of a suspected underground nuclear explosion in order to identify and locate a cavity by processing and analysis of seismic records.

***T2.1-04** "Seismic Full Moment Tensor Analysis of Nuclear Explosions in North Korea" estimates full moment tensors and their uncertainties for the six nuclear tests in the Democratic People's Republic of Korea, a cavity collapse at the test site immediately after a test, and two earthquakes and finds that the moment tensor source types are clearly separated.

***T2.1-05** "Seismic Spectral Ratios Between North Korean Nuclear Tests: Implications for Their Seismic Sources" estimates the burial depth and yield of the source of the nuclear test by the Democratic People's Republic of Korea constrained by spectral ratios.

***T2.1-06** "The 2017 North Korean Nuclear Test - A Comprehensive Multi-Technology Analysis" presents a multi-technology and multi-methodology analysis indicating that the event in the Democratic People's Republic of Korea in September 2017 was indeed a nuclear test, verifying the readiness of the CTBTO even before the Treaty's entry into force.

***T2.1-07** "UK NDC Analysis of IMS Radionuclide Events Near to North Korea" examines the contribution of civil and non-civil radioxenon emitters to IMS radionuclide station RN38 in Takasaki, Japan, and how this affects the IMS sensitivity to the test site in the Democratic People's Republic of Korea.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T2.1-P1 "A Seismo-Acoustic Analysis of the 2017 North Korean Nuclear Test" shows that a joint analysis of seismic and acoustic CTBTO data improves nuclear test monitoring and verification.

T2.1-P4 "Applying Radioxenon Isotopic Ratios for Nuclear Explosion Monitoring" demonstrates that visualizations and statistical tests could potentially be applied for CTBT monitoring purposes.

T2.1-P5 "Automatic Computation of MSVMAX Magnitude at the French National Data Center" presents an operational tool based on magnitudes that helps to discriminate between earthquakes and explosions.

T2.1-P6 "Candidate Methods for the Implementation of OSI Resonance Seismometry" discusses resonance seismometry, a not so well established method that is planned to be used in future OSI field exercises.

T2.1-P9 "Comparison of the DPRK Aftershocks Observed in 2019 with the Aftershocks Between September 2016 and April 2018" examines dozens of low magnitude aftershocks in the Democratic People's Republic of Korea that were identified by the cross-correlation method and concludes that the test site has not reached equilibrium state.

T2.1-P11 "Detection of Nuclear Explosions by Remote Regional Seismic Network" analyses three nuclear explosions recorded by the Baltic Virtual Seismic Network and concludes that it is possible to use remote seismic networks for the monitoring of nuclear explosions.

T2.1-P12 "Determination of Body-Wave Magnitudes of the North Korean Underground Nuclear Tests" presents the use of waveform data and conventional methods to precisely and accurately determine the magnitudes of the underground nuclear tests in the Democratic People's Republic of Korea.

T2.1-P13 "Explosion Monitoring Research at the Nevada National Security Site" presents the Underground Nuclear Explosion Signatures Experiment, a project that focuses on improving models for late time signals produced by underground explosions and includes the study of remote sensing and geophysics methodologies to detect changes in the surface and subsurface after historic explosions, and its experimental studies to measure and model tracer gas migration in different emplacement scenarios of past nuclear explosions.

T2.1-P14 "Focal Mechanism of 2017 DPRK Nuclear Explosion and Its Collapse Event" improves our understanding of the nuclear explosion and collapse source process and differentiates between the two events on the basis of their focal mechanisms.

T2.1-P15 "Identification of Quarry Blasts Near BRMAR Seismic Array: An Application of Multichannel Cross-Correlation Detector" presents new detection and analysis techniques that allow us to observe even smaller events with greater accuracy and to identify and characterize events such as quarry/mining blasts and chemical/nuclear explosions.

T2.1-P16 "Infrasound Signals from the 2017 North Korean Underground Nuclear Explosion and the Subsequent Collapse Event" focuses on the assessment of infrasound signals from the underground nuclear explosion and subsequent collapse event on 3 September 2017 in the Democratic People's Republic of Korea and the improvement of atmospheric model prediction.

T2.1-P17 "Overview of North Korean Nuclear Tests Based on Data from Modernized Slovak National Network of Seismic Stations" presents how the Slovak National Network of Seismic Stations detected the nuclear tests conducted by the Democratic People's Republic of Korea.

T2.1-P19 "Radionuclide Signatures of Molten Salt Reactors" looks at the release of radionuclides from molten salt reactors and its impact on the IMS to improve our understanding of how radionuclide signatures can be confused with those from a nuclear explosion.

T2.1-P20 "Relative Location of DPRK Test Events" derives the relative locations of the six nuclear tests in the Democratic People's Republic of Korea on the basis of data from stations that detected all of the tests and provided good azimuthal coverage, as well as good coverage in time and frequency.

T2.1-P21 "Relative Location of North Korean Nuclear Tests Using IMS Data: How Do Different Techniques Compare?" evaluates different ways to relatively locate the nuclear test sites in the Democratic People's Republic of Korea using IMS data and assesses their suitability for routine nuclear test monitoring.

T2.1-P22 "Relocation of Seismic Events in South Africa for Ground Truth Identification and Classification" presents efforts to improve the velocity models used in the calculation of travel time corrections for regional phases by relocating well-located earthquakes and classifying them as ground truth.

T2.1-P23 "Representation of Complex Seismic Sources by Orthogonal Moment Tensor Fields" proposes a new theory to describe and quantify the complexity of seismic sources such as earthquakes and explosions.

T2.1-P24 "Seismological Investigations of the 2017 North Korean Nuclear Test" analyses the nuclear test in the Democratic People's Republic of Korea in September 2017 and the event shortly thereafter and estimates that the nuclear test had a body wave magnitude of 6.2 and a yield estimate equivalent to 400 kT TNT and that the subsequent event was a cavity collapse at 600 m depth.

T2.1-P26 "Source Time Functions of North Korean Nuclear Tests" computes the seismic source time functions of the underground nuclear tests in the Democratic People's Republic of Korea directly from seismograms and calibrates their yield using data on similar rocks from the Nevada National Security Site in the United States of America.

T2.1-P27 "Space Borne Optical and Radar Data to Characterize North Korean Nuclear Test 2017" suggests using space-borne remote sensing to detect surface deformations related to underground nuclear tests.

T2.1-P28 "Summary of Common Exercise (Waveform Portion) at the 6th East Asia Regional NDC Workshop 2018" presents findings from the East Asia Regional National Data Centre Workshop, during which 10 NDCs and the IDC exchanged waveform analyses on the six announced nuclear tests by the Democratic People's Republic of Korea.

T2.1-P29 "The Detection of Underground Nuclear Explosions by Natural Signatures" proposes a new approach to detect underground nuclear tests using natural signatures produced from the increased release of radon gas isotopes (^{222}Rn and ^{220}Rn) from the disturbance and pressurization of the subsurface flow regime caused by an underground nuclear explosion.

T2.1-P30 "Three-Dimensional Space Analysis of Radioxenon Isotopic Activity Ratios for Characterizing a Nuclear Event" presents a study on nuclear release timing aimed at analysing radioxenon isotopic activity ratios in three-dimensional space that shows promising results for nuclear event zero time determination and nuclear release discrimination when real data from nuclear tests are used.

T2.1-P31 "Towards an Improved Catalogue of Shallow Ground Truth Events in Eastern North America" extends the set of ground truth events with known depths and shows how this can be used to refine methods for estimating depths and therefore discriminate nuclear events from earthquakes.

T2.1-P32 "Underground Nuclear Explosions on the North Korean Test Site According to the KNET Network Data" presents a comparative analysis of the waveforms of the nuclear tests by the Democratic People's Republic of Korea according to Kyrgyz Seismic Network (KNET) data and estimates the dynamic and kinematic parameters of the explosions.

T2.1-P34 "Yield Estimates for the DPRK's Sixth Nuclear Test with Radar and Seismic Analysis" studies the nuclear test by the Democratic People's Republic of Korea in September 2017 and the smaller event shortly thereafter on the basis of satellite radar observations and seismic analysis and finds depth, cavity radius and estimated yield results that differ from those of other studies.

T2.2 Challenges of On-Site Inspection

Highlights

Presentation *A Rapid and Non-Destructive Method for Determining In-Situ Uniaxial Compressive Strength (UCS) of Rocks During On-Site Inspections* (**T2.2-01**) described a test technique to rapidly assess the condition of rocks. The use of such a technique during an OSI would help to enable prompt determination of the nature and characteristics of in situ rocks and facilitate the application of other OSI techniques.

Presentation *CHAOS During an OSI (Applying Measurement Restrictions to Sample Characterisation at the BOO)* (**T2.2-02**) presented a ruggedized, gamma–gamma based system for in-field measurement of environmental samples developed by radionuclide laboratory RL15 (United Kingdom). The system was specifically designed to measure only the 17 OSI relevant radionuclides, with no information recorded on any other radionuclides that might be present in a sample. The software is fully configurable depending on the level of measurement restrictions required.

Presentation *Gamma Imaging for On-Site Inspection: Reconstruction of an Extended Source in a Restricted-Access Zone* (**T2.2-05**) described a new silicon photomultiplier-based Compton telescope gamma imager and survey spectrometer that was developed for use in a simulated OSI restricted access site to perform a sort of triangulation to characterize the distribution of radioactivity. Experimenters developed tomographic methods to reconstruct the distribution of the test sources used. Despite the imager being constrained to locations on the ground over 200 m from the source, it is possible to localize the distribution of radioactivity.

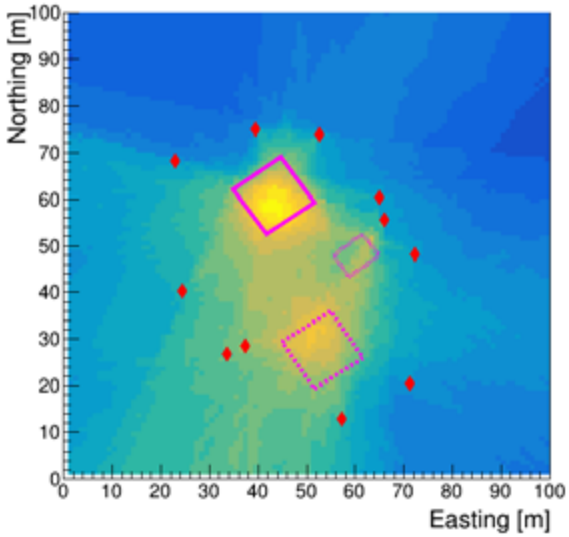


Figure 18. Compton imaging tomography reconstructed source as measured from the borders of a restricted access area. From N. Murtha et al. (T2.2-05).

Presentation *The Potential Use of Interferometric Techniques in the Location and Size Estimation of Suspected Test Sites* (**T2.2-08**) showed interferometric instrumentation that can be mounted on drones and used at relatively low elevation, providing a very dense cloud of observations with high spatial resolution. In combination with open-source satellite images, drone borne interferometry offers a low cost way to identify the location of a suspected underground nuclear explosion. This would be a valuable addition to OSI visual observation techniques. The potential utility of this technique to detect ground deformation was shown using the last nuclear test by the Democratic People's Republic of Korea as an example.

Presentation *Utilization of Unmanned System for Environmental Sampling in CTBT OSI* (**T2.2-09**) demonstrated the use of unmanned systems for environmental sampling in harsh or hazardous environments, such as those contaminated with high or lethal levels of radioactivity. A prototype of such a system has been tested in both laboratory and field conditions. The results to date suggest that the system functions well in harsh conditions and offers significant advantages for OSI in terms of communications, navigation, reliability, durability, ease of maintenance and mobility.

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

***T2.2-01** "A Rapid and Non-Destructive Method for Determining In-Situ Uniaxial Compressive Strength (UCS) of Rocks During On-Site Inspections" addresses OSI verification technology and techniques according to OSI action plan projects, among which is the further development and consolidation of inspection activities and techniques.

***T2.2-02** "CHAOS During an OSI (Applying Measurement Restrictions to Sample Characterisation at the BOO)" presents coincidence based high resolution analysis for OSI spectrometry (CHAOS), the first gamma–gamma based system to provide real-time traditional and coincidence based gamma spectrometry in an easy to use, automated package, which greatly improves the reliability and consistency of environmental monitoring whilst restricting access to sensitive information.

T2.2-03 "Cs-137 Background Measurement in the Marine Environment of the Asia-Pacific Region to Support Emerging Challenges of On-Site Inspection (OSI) in Seas" provides new information on ^{137}Cs background concentrations in seawater, sediment and biota from the Asia-Pacific region for future use as reference/background data, including for OSI.

***T2.2-05** "Gamma Imaging for On-Site Inspection: Reconstruction of an Extended Source in a Restricted-Access Zone" shows how a gamma imager deployed at the perimeter of a restricted access zone during an OSI can resolve the shape of radioactivity distribution inside the excluded zone without entering that zone.

T2.2-07 "How to Develop a Credible Scenario for Large Field Exercises - Scenario Task Force Activities" provides an overview of the objectives, scope and method of work of the scenario task force, the challenges faced in creating a complex scenario, and the means by which an OSI scenario may stimulate the application of inspection techniques and inspection elements.

***T2.2-08** "The Potential Use of Interferometric Techniques in the Location and Size Estimation of Suspected Test Sites" adds to the potential methods used during OSIs to rapidly and accurately locate a suspected nuclear test site.

***T2.2-09** "Utilization of Unmanned System for Environmental Sampling in CTBT OSI" promotes the use of an unmanned system to reduce the risk of exposure to a dangerous environment and improve the efficiency of an OSI.

T2.2-010 "UNE's Subsurface Signatures, Detected by Active Seismic Surveys at the Semipalatinsk Test Site" suggests the use of active seismics to detect shallow zones of rock disintegration, such as spall zones, to provide quick information about the hypocentre locations for borehole underground nuclear explosions.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T2.2-P3 "Business Approach to Finish an Unsolved Dilemma of the OSI" addresses the issue of false ^{135}Xe detections due to medical radioisotope production and suggests as a solution that the released xenon be re-commercialized.

T2.2-P6 "ESI 2007 Earthquake Intensity Scale in Help of CTBT OSI's Verification Regime" presents the environmental seismic intensity scale as of 2007 (ESI 2007), which was designed, implemented and tested to measure the damage level of an earthquake by solely focusing on the impact to nature, and its commonalities with OSI visual observation.

T2.2-P8 "Studying the Suspected Site of Nuclear Test by Using Microtremor Method" explores the idea that every site has its own frequency, and that these frequencies vary depending on the location and composition of the site and change if part of the site is destroyed.

T2.2-P15 "VNIIA Major Activities Related to the CTBT Technologies" presents the activities of the All-Russian Research Institute of Automation (VNIIA), such as the provision of scientific and methodological support to OSI activities, improvement of the information and analytical system and development and upgrading of e-training software and noble gas monitoring equipment.

T2.3 Seismoacoustic Sources in Theory and Practice

Highlights

Presentation *Analysis Result of DPRK's Nuclear Test Using Korea Meteorological Administration (KMA) Infrasound Network* (**T2.3-01**) analysed the detection capabilities of an improved network of sensors deployed in the Republic of Korea close to the border with the Democratic People's Republic of Korea. The previous network showed good detection capability of nuclear tests, cavity collapse and missile tests by the Democratic People's Republic of Korea. The data from the Korea Meteorological Administration infrasound network were compared with data from IMS infrasound station IS45. The improved network will follow CTBTO standards. Data from this network is interesting for the CTBTO because all recently announced tests were conducted at sites in the Democratic People's Republic of Korea.

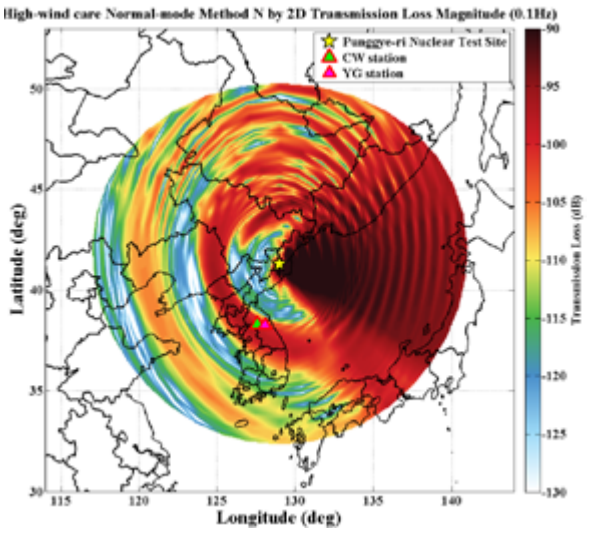


Figure 19. Infrasonic propagation modeling result using the Korean Meteorology Administration's atmospheric data for the nuclear test in the Democratic People's Republic of Korea in January 2016. From Y. Jeon et al. (T2.3-01).

The objective of presentation *Analysing the Reduced Displacement Potentials of DPRK Nuclear Explosions Using Waveform Equalization Technique* (**T2.3-02**) was to estimate the burial depth of a nuclear test based on available data from the Global Seismographic Network of the Incorporated Research Institutions for Seismology (IRIS) using the waveform equalization technique. The applied method worked well for smaller sources but failed to determine the actual burial depth for the largest explosion in the Democratic People's Republic of Korea in 2017 owing to the influence of non-isotropic sources. The depth of a source is one of discriminants between an explosion and a natural event, thus of high importance to the CTBTO.

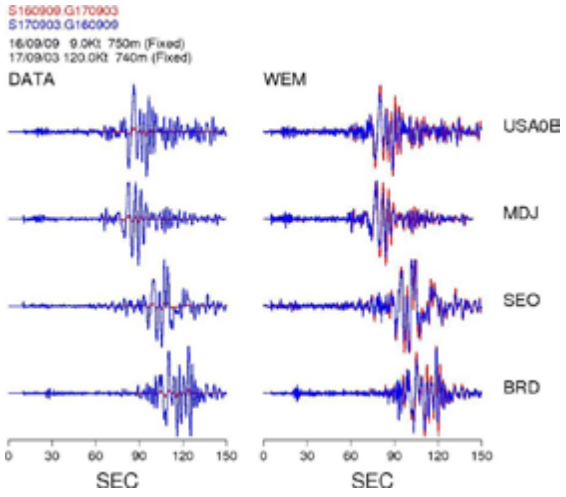


Figure 20. Analysing the reduced displacement potential of the sixth nuclear explosion of the Democratic People's Republic of Korea using the waveform equalization method, with fixing the reduced displacement potential of the fifth nuclear explosion and fixed depth. From C. Saikia. (T2.3-02).

Presentation *Data Analysis and Simulations of the Source Physics Experiments: Impact on Explosion Discrimination & Monitoring* given (**T2.3-03**) reported on source physics experiments (SPEs) conducted at the Nevada National Security Site in the United States of America to validate the results of numerical calculations. Two series of different depth explosions were carried out. Signals from explosions were investigated at both close (near-field) and larger distances. Explosion generation of shear waves, signals more typical for natural sources, was of special interest. Discrimination between natural and man-made events, which was of special interest for the SPEs, is an important role of the CTBT verification system. This oral presentation was also followed by a series of posters on this topic.

Studies of these sources will help to advance methods to discriminate between man-made explosive events and natural sources. There were a few other posters on the discrimination of events, however they were not related to SPEs.

Several presentations, including *A New GT5 Event in a Previously Aseismic Region of the Brazilian Phanerozoic Parnaiba Basin* (**T2.3-P1**) and *Estimating Seismic Source Depths Using Body and Surface Wave Observations* (**T2.3-P13**) focused on earthquake source and propagation medium characterization, which will help

to improve location precision. Presentations included ground truth events in low seismicity areas or investigation of the influence of explosion source area on seismic waveform patterns.

One poster, *Analysis of the Infrasound Signals from a Bolide Over the Bering Sea* (**T2.3-P5**), described findings of a study of a large fireball, which is a Treaty-relevant source captured by infrasound stations. An attempt of yield estimate was made. The currently listed infrasound Reviewed Event Bulletin events do not have magnitude as one of their parameters.

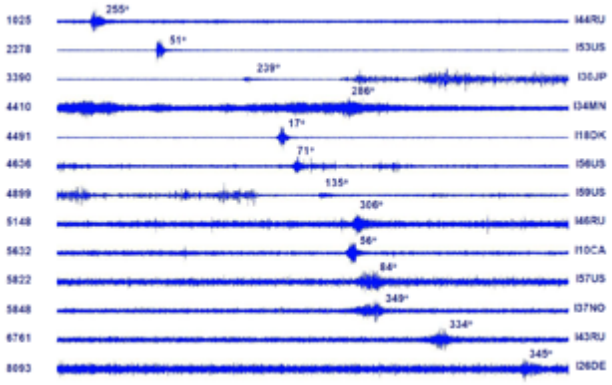


Figure 21. Filtered beams exhibiting infrasound signals from a bolide that exploded over the Bering Sea sorted against the distance: distance in kilometres shown on the left, name of IMS infrasound arrays shown on the right, while the numbers above the signals are the estimated source/receiver azimuth. From P. Negraru and G. Johnson. (T2.3-P5).

Poster presentations also confirmed the trend that some National Data Centres (e.g. Iraq) have joined the CTBT monitoring efforts and incorporated IMS data for training and routine activities.

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

***T2.3-01** "Analysis Result of DPRK's Nuclear Test Using Korea Meteorological Administration (KMA) Infrasound Network" presents the duties of the Korean Meteorological Administration as a government organization and its current work on infrasound analysis and infrasonic network expansion.

***T2.3-02** "Analysing the Reduced Displacement Potentials of DPRK Nuclear Explosions Using Waveform Equalization Technique" demonstrates a new algorithm that can estimate the source reduced displacement potential and depth of burial when seismograms from multiple nuclear explosions are available at a common station.

***T2.3-03** "Data Analysis and Simulations of the Source Physics Experiments: Impact on Explosion Discrimination & Monitoring" shows how improved source-to-receiver models enable understanding of observed seismic signals and improved discrimination ability in new geologies.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

***T2.3-P1** "A New GT5 Event in a Previously Aseismic Region of the Brazilian Phanerozoic Parnaiba Basin" presents a study on a new ground truth 5 event to better define the 3-D velocity model for Brazil.

T2.3-P3 "Analysis and Modelling of the Infrasound Signals from the 2017 DPRK Nuclear Explosion at IMS Station IS45" numerically models identified infrasonic phases and applies 2-D ray tracing and 1-D parabolic equation methods with atmospheric velocity profiles derived from a forecast model from the European Centre for Medium-Range Forecasts augmented by empirically deduced velocity variations and concludes that both stratospheric and thermospheric ducting had occurred, which explains the presence of two major peaks related to the explosion and the aftershock signal generated by the cavity collapse 25 minutes later.

T2.3-P5 "Analysis of the Infrasound Signals from a Bolide over the Bering Sea" discusses IMS infrasound observations from a powerful bolide over the Bering Sea in December 2018, which were used to obtain the source location and origin time using the Bayesian infrasound source location procedure and estimate an energy release between 5 kt and 103 kt.

T2.3-P6 "Complex Seismological Investigations near Bulgarian Antarctic Base" describes methods and velocity models used to determine earthquake locations on the basis of thousands of seismic events recorded at the Bulgarian Antarctic seismic station as well as the techniques used to study glacial seismicity.

T2.3-P9 "Detection and Interpretation of Seismoacoustic and Seismic Events at NDC Iraq" analyses an explosion at a Ukrainian ammunition depot using IDC products and data from infrasound stations and a seismic event at the Iran–Iraq border using NDC in a box software.

T2.3-P12 "Distributed Acoustic Sensing Observations and Modeling of the DAG Series of Chemical Explosions" presents data that give unprecedented resolution in tracking near-source explosion-generated seismic P-waves, S-waves and damage.

***T2.3-P13** "Estimating Seismic Source Depths Using Body and Surface Wave Observations" describes an improved approach to seismic source depth estimation for use in nuclear test monitoring and verification.

T2.3-P16 "Hybrid Waveform Modeling for Small-Scale Source Complexity at Teleseismic Distances" uses hybrid waveform modelling to distinguish and identify observables generated by historic underground nuclear explosions.

T2.3-P17 "Implications for S Wave Generation from Subsurface Chemical Explosions Using Large Arrays of Sensors" explains how using a dense seismic array to record similar chemical explosions in different geological materials has yielded improvements to S-wave modelling and potential improvements to discrimination algorithms.

T2.3-P19 "Infrasound Monitoring of Deorbiting Soyuz Crafts on the Territory of Central Kazakhstan" characterizes the acoustic and seismic signals from the deorbiting Soyuz crafts.

T2.3-P20 "Measurement of Rotational Ground Motions for CTBT" compiles some of the major advantages of measuring rotational ground motion using broadband rotational instruments and provides an outlook for possible applications within the framework of the CTBT.

T2.3-P22 "Seismic Moment Tensor Inversion for Source-Type Identification" attempts to understand the calculation uncertainty in seismic moment tensors, as station configurations and geology vary.

T2.3-P23 "Simultaneous Relocation of the Seismicity of the Pannonian Basin Using Bayesloc" presents how the Bayesloc multiple event location algorithm was used to relocate the entire seismicity of the Pannonian Basin, resulting in the identification of the most accurate hypocentres in the region to date.

T2.3-P24 "Source Models and Scattering Origin of Regional Phases from Coda Spectral Ratios" presents how the source physics experiments allow the enhancement of nuclear test monitoring and verification through testing classical explosion source models and identifying the source of local and regional body waves as Rg that is scattered in the near-source region.

T2.3-P25 "Study of Seismoacoustic Signatures of the September 28th 2018 Sulawesi Earthquake" presents a detailed study of the magnitude 7.5 earthquake and subsequent tsunami in September 2018 near the city of Palu in Indonesia, including event related observations and the potential infrasound generation mechanisms covering range- and time-dependent infrasound propagation modelling, realization and variation of the atmospheric background conditions as well as comprehensive data analyses of a large number of infrasound stations in the area, some of which showed additional signal features possibly related to the event.

T2.3-P26 "The Annual Hungarian Seismo-Acoustic Bulletin of Ground Truth Events" presents all of the identified ground truth events detected by the infrasound array of the Hungarian network in its first year of operation.

T2.3-P27 "The Baumgarten and Ingolstadt Explosions: Infrasound Observations from Ground Truth Sources in Eastern Austria and Southern Germany" analyses the infrasound signals of two strong explosions at gas/oil facilities using frequency–wavenumber techniques and cross-correlation analysis to extract relevant waveform parameters of the observed arrivals and uses seismic arrivals to estimate the seismic magnitude of each explosion in order to assess the modelling accuracy of the acoustic arrivals.

T2.3-P30 "Waveform and Dispersion Modelling Using DPRK Regional Seismograms Recorded by the High Sensitivity Seismic Network of Japan" illustrates the application of waveform equalization to estimate the source parameters of nuclear explosions using Green's functions developed from the inversion of the Rayleigh and Love wave dispersion values.

T2.3-P31 "Near-Source Mechanism for Creating Shear Content from Buried Explosions" applies source physics experiment data to develop a new analytical model that appears to be relevant to the interpretation of monitoring data.

T2.4 Atmospheric and Subsurface Radionuclide Background and Dispersion

Highlights

Presentation *The Detection of Ar-39 Above UNEs Decades Later as a Signature* (**T2.4-09**) showed that relevant progress has been made by Pacific Northwest National Laboratory (PNNL) in different measurement campaigns at the Nevada National Security Site, where high levels of ^{39}Ar originating from old nuclear tests were detected. In addition, in *Underground Nuclear Explosion Signatures Experiment (UNESE) Phase 2: Gas Migration Studies in a Tunnel Test Location* different diffusion mechanisms were studied by using injections of ^{37}Ar and ^{127}Xe in the old facility tunnel (**T2.4-010**).

In presentation *Analysis of High Time-Resolution Observations of Radioxenon Releases from BWRs Compared to Stack Data and Reactor Operation Parameters* (**T2.4-01**), the Swedish Defence Research Agency (FOI) demonstrated the successful application of the Swedish regional dispersion model Pello, which uses as an input high resolution meteorological data from the European Centre for Medium-Range Weather Forecasts (ECMWF) with horizontal resolution 0.1 times 0.1 degree. The model was applied to analyse 6 hour time resolution xenon nuclear power plant emissions data versus measurements.

Presentation *Assessment of Temporal Variations of Natural Radionuclides Beryllium-7 and Lead-212 in Surface Air in Tanay, Philippines* (**T2.4-03**) showed that for radionuclide station RN52 (Philippines) there is a high correlation between ^{212}Pb and temperature and ^{212}Pb and relative humidity. Beryllium-7 and ^{212}Pb are not correlated. It was suggested that the high correlation between ^{212}Pb and relative humidity may be caused by a different filter dimension as a result of humidity expansion.

Presentation *Half a Century of Krypton-85 Measurements in the Atmosphere of Central Europe* (**T2.4-05**) demonstrated that it was possible to estimate inter-hemispheric exchange of ^{85}Kr. It turns out that large quantities of ^{85}Kr are released into the atmosphere as a result of nuclear reprocessing.

Presentation *High Resolution Stack Data from Fission Based Mo-99 Production* (**T2.4-06**) provided an update related to the status of the Source Term Analysis of Xenon (STAX) project. The project uses high resolution stack detectors to directly measure the four radioxenon isotopes with temporal frequency of 15 minutes. Currently, the data are collected at the Australian Nuclear Science and Technology Organisation (ANSTO) and the National Institute for Radioelements (IRE) in Belgium. Data help to rethink some assumptions by which data from medical isotope production facilities end up in the multi-isotopes plot and therefore are characterized as peaceful use as opposed to nuclear test scenarios.

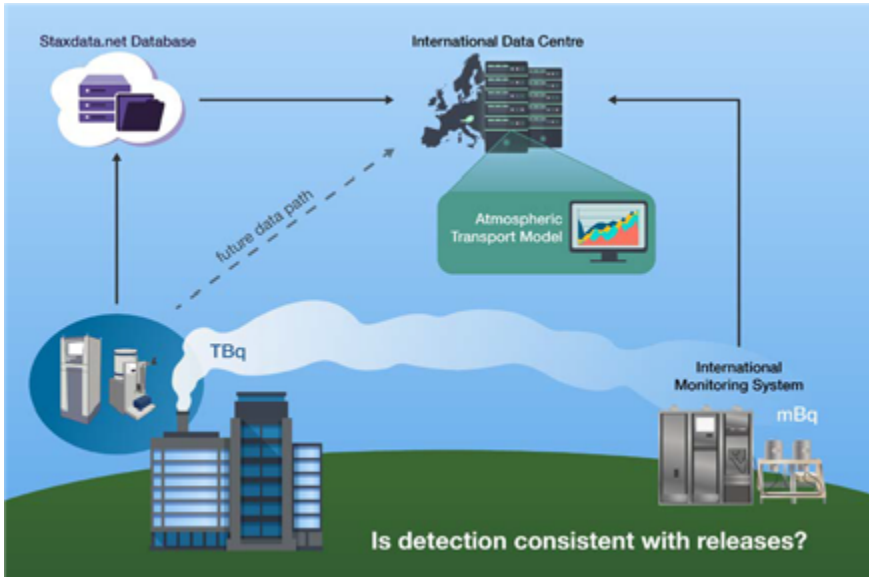


Figure 22. The Source Term Analysis of Xenon (STAX) project seeks to procure and install an experimental network of stack monitoring systems at isotope production facilities to assist in monitoring for signatures of nuclear explosions. From J. Friese et al. (T2.4-06).

Overview of Oral Presentations

***T2.4-01** "Analysis of High Time-Resolution Observations of Radioxenon Releases from BWRs Compared to Stack Data and Reactor Operation Parameters" compares data with stack and other operational data in combination with different atmospheric transport models as well as calculations of different nuclear production and separation scenarios to gain a better understanding of the observed plume shapes and isotopic ratios.

T2.4-02 "Application of Computational Fluid Dynamic in the Atmospheric Dispersion of Radionuclides at Fukushima Disaster" shows how the Fukushima accident, being one of the most relevant since the Chernobyl disaster, remains an unparalleled opportunity to generate knowledge and add value in monitoring the atmospheric dispersion of radionuclides.

***T2.4-03** "Assessment of Temporal Variations of Natural Radionuclides Beryllium-7 and Lead-212 in Surface Air in Tanay, Philippines" discusses how air particles are distributed in the surface air, particularly in countries with tropical climates, thus mitigating significant effects on the environment and human health.

T2.4-04 "Contribution of All Nuclear Research Reactors to the Global Radioxenon Emission Inventory" presents a first attempt to assess the total emission inventory of nuclear research reactors expressed as annual total discharges to potentially guide future studies and enhance understanding of the impact of known sources on IMS background observations.

***T2.4-05** "Half a Century of Krypton-85 Measurements in the Atmosphere of Central Europe" presents air samples going back almost 50 years for the measurement of ^{85}Kr, an indicator of clandestine plutonium production.

***T2.4-06** "High Resolution Stack Data from Fission Based Mo-99 Production" presents a detector technology and some sample data from the direct measurement of radioxenon releases from an operating medical isotope production facility and offers a unique look into the contributions these facilities make to the worldwide radioxenon background.

T2.4-08 "Search for Radioxenon Signals at IMS Stations Possibly Associated with Announced DPRK Nuclear Tests" applies best methods to extract any signal from radioxenon observations that may indicate a nuclear test using historic tests by the Democratic People's Republic of Korea as case studies.

***T2.4-09** "The Detection of Ar-39 Above UNEs Decades Later as a Signature" concludes that radionuclide signatures from underground nuclear explosions are easily detectable for decades, a paradigm shift from current efforts to use nuclear explosion monitoring techniques based on observables that disappear quickly as a result of decay, dispersion and possible concealment efforts.

***T2.4-010** "Underground Nuclear Explosion Signatures Experiment (UNESE) Phase 2: Gas Migration Studies in a Tunnel Test Location" presents measurements taken over a six month period after the injection of sulphur hexafluoride and the radioactive tracers ^{127}Xe and ^{37}Ar into a horizontally emplaced nuclear explosion chimney, providing a unique opportunity to explore evolution and transport of gaseous tracers in the subsurface.

T2.4-011 "Backgrounds, False Negatives and False Positives: Dealing with RN Detection in 2019" provides a policymaker level discussion of backgrounds, making the case through atmospheric transport modelling and Kalinowski plot simulations that backgrounds that are not subtracted result in both false positive and false negative detections.

Overview of Poster Presentations

T2.4-P1 "Aerosol Dynamics and Dispersion of Radioactive Particles" shows that various aerosol dynamic processes during transport need to be properly addressed in dispersion modelling, using the trajectory box model CALM (chemical and aerosol Lagrangian model) to simulate them.

T2.4-P2 "Application of Source Detective System for a Fukushima Accident" focuses on evaluating the unknown source information of radionuclides in the atmosphere measured at IMS stations.

T2.4-P3 "Argon-37 Variability in the Low Troposphere" examines the variability of ^{37}Ar measurements collected close to IMS radionuclide station RN38 in Takasaki, Japan, in the years 2016-2018.

T2.4-P4 "Assessment of Radionuclides Present in Atmospheric Aerosol in Dar Es Salaam, Tanzania by Using Gamma-Ray Spectrometry" assesses radionuclides present in atmospheric aerosol collected from the IMS radionuclide station RN64 (Tanzania) by gamma ray spectrometry in order to establish the background radioactivity level of the atmosphere.

T2.4-P5 "Atmospheric Dispersion and Ground Level Deposition of Cs-137 Released from Chernobyl Nuclear Power Plant Accident" presents a simulation of atmospheric dispersion and ground level deposition of ^{137}Cs released from the Chernobyl nuclear power plant based on the Lagrangian particle dispersion model FLEXPART using reanalysis data sets from the European Centre for Medium-Range Weather Forecasts and the National Centers for Environmental Protection as meteorological input data to find a better representation of ^{137}Cs depositions.

T2.4-P6 "Atmospheric Dispersion Assessment of Radioxenon after North Korea's 6th Nuclear Test Using LADAS Model" presents atmospheric dispersion simulations on some radioxenon emission scenarios for the underground nuclear test by the Democratic People's Republic of Korea using the Lagrangian Atmospheric Dose Assessment System (LADAS) model.

T2.4-P10 "Atmospheric Dispersion of Radionuclides Originating from Hypothetical Accidents and Normal Operation in Research Reactors and Medial Production Facilities" presents results of emission from normal operation of research reactors and medical isotope production facilities and examples of hypothetical accidents and analyses the contributions of radionuclides released to the atmosphere and the contributions from noble gases, iodine/bromine and aerosols.

T2.4-P13 "Atmospheric Transport Modelling for Dispersion Conditions After the DPRK 2017 Nuclear Test and the Origin of Regional Xenon Detections" shows that although radioxenon detections in the Republic of Korea after the September 2017 test in the Democratic People's Republic of Korea seem to originate from the region of the Yongbyon nuclear facility, detections of ^{133}Xe during October 2017 are fully consistent with a delayed small leakage at the test site.

T2.4-P14 "Atmospheric Transport Study of Japan Noble Gas Systems" provides a deeper understanding of the influence of known background sources on IMS radionuclide station RN38 (Japan).

T2.4-P15 "Backward Atmospheric Transport Modelling Coincidence Localization of Single Sources and Repeating Emitters" expands the simple additive coincidence approach overlapping source–receptor sensitivity fields for multiple detections to evaluate source regions of repeating radioxenon detections at single stations and shows recent examples from different IMS radionuclide stations.

T2.4-P16 "Characterization and Evolution of Global Xe Background Between 2016 and 2018" conducts a comparative study between the global radioxenon background in 2016, 2017 and 2018 to determine the evolution of the radioxenon background for all available IMS stations.

T2.4-P20 "ECMWF Data Sets as Input for the ATM FLEXPART Prepared by a New Version of the flex_extract Tool" argues that efficiently retrieving and selecting data from the European Centre for Medium-Range Weather Forecasts (ECMWF) for applications in transport modelling with FLEXPART, which is essential for the quality of nuclear test verification, as well as continuous adaptation, quality assurance and dissemination updates, will increase reliability.

T2.4-P21 "Establishment of the National Baseline Using Data from IDC" shows how to make use of IDC products as a tool for radiation monitoring for public safety and also as a preliminary guideline for decision making in case of nuclear incidents.

T2.4-P22 "Estimation of the CTBT-Relevant Radionuclides Sources by Ensemble Adjoint Atmospheric Transport Modelling" attempts to answer the questions of how to estimate the source of radionuclide detections using ATM and how to quantify the uncertainty in this estimation.

T2.4-P23 "Estimation of Xenon Background for the IMS Stations Located in the Pacific Ocean" combines atmospheric transport modelling results with ^{133}Xe observations to estimate the xenon background over a period of nine months and demonstrates that nuclear power plant emissions can significantly contribute to ^{133}Xe measurements, even at remote locations.

T2.4-P25 "Fractional Release of Argon from Activated Rocks and Powders" takes a first step in quantifying the emanation fraction of radionuclides and demonstrates that measurable quantities of argon may be released.

T2.4-P26 "Global Observations of Radioiodine by the CTBT International Monitoring System" studies the potential of detecting evidence for nuclear explosion signals through radioactive iodine in the atmosphere in view of all IMS observations.

T2.4-P27 "Global Radioxenon Emission Inventory for 2014 by Normal Operational Releases from Nuclear Power Plants and Medical Isotope Production Facilities" presents the best estimate of the global radioxenon background based on all existing sources of the global radioxenon emission inventory, so as not to miss a nuclear explosion signal in the presence of radioxenon background.

T2.4-P28 "Hemispheric Atmospheric Dispersion Analysis of Radionuclides Released from the Fukushima Daiichi Nuclear Power Plant" analyses hemispherical atmospheric dispersion of ^{137}Cs released from the Fukushima Daiichi Nuclear Power Plant in March 2011 and finds that the ^{137}Cs released on 12-14 March was dispersed almost all over the northern hemisphere and that most of the ^{137}Cs observed in Europe is due to the release during this period, whereas the ^{137}Cs released on 17-19 March mainly reached the Pacific Islands area and the west coast of the United States of America.

T2.4-P29 "How the UK National Data Centre Utilises Stack Monitoring Data in Support of the Comprehensive Nuclear Test-Ban Treaty" presents tests by the National Data Centre of the United Kingdom of a Source Term Analysis of Xenon (STAX) project prototype data stream by means of analysing 11 months of data from the Institute for Radioelements in Belgium.

T2.4-P30 "Impact of CRL Shutdown on CTBTO North-American Noble Gas Stations" shows how the shutdown of the Chalk River medical isotopes production facility in Canada will be exploited to better understand how it impacted the noble gas stations of the IMS and final IDC products.

T2.4-P32 "Impacts of Tropical Climate on Radioactivity Measurement in Particles Collected at the Recently Certified RN65, Thailand" reveals the impact of tropical climate factors, including ambient temperature and humidity, on the background radioactivity level of radionuclides of interest.

T2.4-P33 "Inhalation Dose Assessment of ^{212}Pb and ^{7}Be Using Data of IMS RN65" uses activity concentrations of natural radionuclides such as ^{7}Be and ^{212}Pb reported in the Reviewed Radionuclide Report to assess the inhalation dose for people living near radionuclide station RN65 (Thailand).

T2.4-P34 "Introducing Geomechanics and Discrete Fracture Capabilities into STOMP to Understand the First 10-100m of UNE Signal Transport" discusses how the additions of direct geomechanical stress and discrete fracture simulation capabilities into transport codes such as STOMP are critical to furthering understanding of early time evolution of radionuclide signatures in the immediate vicinity of an underground nuclear explosion.

T2.4-P35 "Inverse Modelling Applied to the Xe-133 Background" uses ^{133}Xe detections (and non-detections) at specific stations in the northern hemisphere, applies inverse modelling, compares the estimated location and emission to the properties of a major medical isotope production facility, and tests the inverse modelling capability in a real-world environment.

T2.4-P36 "Investigation of Emission of ^{37}Ar from All Nuclear Research Reactors Worldwide" investigates the emission of ^{37}Ar starting from specific research reactors and then extrapolates to all nuclear research reactors worldwide.

T2.4-P37 "Investigation of Specific Historical Radioxenon Background Detections in the IMS" contributes to the improvement of nuclear test monitoring and verification, especially to radioxenon monitoring, by providing a better understanding of the radioxenon background observed in the IMS network.

T2.4-P38 "Isotopic Signature of Radioargon Released from the FRM-II Reactor" aims at defining the radioactive argon background produced by civilian nuclear facilities, as accurate source term estimations based on measurements are important for the discrimination of industrial releases from Treaty-relevant events.

T2.4-P39 "Magmas in Nuclear Cavities and Their Potential Effects on the Source Term and Its Migration" evaluates the potential interaction of fission products with magma, their trapping in bubbles, and their transport through a complex matrix made of blocks of rocks surrounded in part by some bubble-bearing magma in order to determine whether this is likely to diminish the activity or modify the source term and the fraction of it that is eventually released to the atmosphere.

T2.4-P40 "Measurement of Radioargon and Radioxenon in Soil Gas" presents preliminary results of analysis of subsoil samples from a location with known elevated uranium content in order to measure the background levels of radioxenon and radioargon in soil gas, along with other components (i.e. radon, CO_2, O_2).

T2.4-P41 "Medical Isotope Production in Argentina: Status of the Construction of RA-10 Research Reactor" presents RA-10, a multipurpose nuclear reactor suitable for radioisotope production, materials and fuel irradiation and neutron techniques applications.

T2.4-P44 "Noble Gas Signature Adsorption in a UNE – Bridging the Gap Between Laboratory and Field Scale Models" dispels the notion that noble gases relevant to underground nuclear explosions are unreactive in the environment by combining numerical modelling using the STOMP code with the results of targeted laboratory-scale gas sorption experiments to interpret seepage in a field campaign.

T2.4-P46 "Progress over 2014 Baseline on the Match Between Observations and Simulations of Radioxenon Concentrations at IMS Stations" compiles results achieved for simulated radioxenon concentration estimates and observations at IMS stations, repeats the statistical analysis of simulated versus observed data and compares the results with the 2014 baseline.

T2.4-P49 "Radionuclides Monitoring Along the Brazilian Coast" presents the efforts of continuous monitoring of radionuclides (^{137}Cs and ^{90}Sr) along the Brazilian coast since 1996 in order to detect any nuclear test or accident in the marine environment in the South Atlantic Ocean.

T2.4-P52 "Statistical Study of the Atmospheric Background and Anomalous Values of the Radioxenon Activity Concentrations at Some IMS Stations" performs a detailed statistical analysis of the atmospheric background and the abnormal concentrations of radioxenon measured at some IMS stations and shows that the control chart for individual measurements is particularly meaningful for the periodic monitoring of IMS stations, whereas the exponentially weighted moving average control chart is more suitable for specific studies on the atmospheric background and on radioxenon activity concentration anomalies.

T2.4-P54 "The Characteristic Release of Noble Gases from an Underground Nuclear Explosion" describes new scientific developments supporting the development of policy objectives and the exchange of pertinent ideas between the CTBTO and the broader scientific community.

T2.4-P56 "Trends in Worldwide Background of CTBT-Relevant Xenon Isotopes Based on IMS Data" compiles trends in the radioxenon background at IMS stations based on seven years of reviewed IDC data.

T2.4-P57 "Validation Study of the Flexpart-WRF Model with Episodes of Xe-133 Releases and Detections in Europe" compares a new high resolution atmospheric transport model to simulate the dispersion of radioxenon against a well-established model and measurements using simulations based on releases from a medical isotope production facility and detections at an IMS station.

T2.5 Historical Data from Nuclear Test Monitoring

Highlights

The reported efforts on historical data from nuclear test monitoring are useful and important for the general understanding of nuclear testing.

Presentation *Noble Gases Release after Underground Nuclear Explosions* (**T2.5-02**) summarized in a statistical way the fraction of underground nuclear tests conducted by the Soviet Union that released radioactive noble gases. It would be very useful if the observed activity releases for every single test were made available. The same applies for releases of other isotopes and for tests conducted by other countries. With such data, the CTBT radionuclide science community could develop and evaluate the effectiveness of refined methods for the detection of nuclear explosion signatures, especially in the presence of a high radioxenon background.

Presentation *Using Satellite Imagery to Map Russia's Underground Nuclear Test Site on Novaya Zemlya* (**T2.5-03**) studied the application of satellite imagery to map the underground nuclear test site in Novaya Zemlya, Russian Federation. The study revealed that many of the locations do not match those listed in official reports. This finding is substantiated by the fact that different original sources about the coordinates of the underground nuclear tests contradict each other. Therefore all countries that conducted nuclear tests in the past should release more detailed and more accurate information about such tests, providing at least the time and location of the event but also depth, yield and other parameters.

Posters *Digitization of Soviet Era Peaceful Nuclear Explosion Seismograms from Regional Stations* (**T2.5-P4**) and *New Stage of Works on Nuclear Explosions Historical Records Digitization* (**T2.5-P8**) provided updates on the progress of ongoing initiatives to digitize analogue seismograms of historic nuclear explosions. This makes analogue seismograms, e.g. from the region of Kazakhstan, usable in the digital era. These data are very useful to validate and optimize current data analysis methods. An easily accessible web interface makes a very large collection of raw and parametric data on nuclear explosions available to the research community (**T2.5–P12**).

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

T2.5-01 "Digitization and Analysis of Printed Seismograms from Aftershocks of the Novaya Zemlya Explosion on October 27, 1973" brings back historical data from seismic aftershocks of nuclear explosions with new methodologies to strengthen today's work on test ban monitoring.

***T2.5-02** "Noble Gases Release after Underground Nuclear Explosions" discusses the release of radioactive noble gases during and after underground nuclear explosions conducted under different conditions of the nuclear device (shaft or tunnel, Semipalatinsk or Novaya Zemlya test site) and provides necessary information for future OSI methodology.

***T2.5-03** "Using Satellite Imagery to Map Russia's Underground Nuclear Test Site on Novaya Zemlya" demonstrates how the use of satellite imagery to develop a baseline of activity at the underground nuclear test site at Novaya Zemlya, Russian Federation, helps to better assess ongoing activity and potential Treaty-relevant events.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T2.5-P1 For the first time, "A Catalogue of Nuclear Test Explosions Recorded by Slovak National Network of Seismic Stations" was compiled from the archives, resulting in seismograms of more than 400 nuclear test explosions that can now be integrated into the worldwide database of nuclear test explosions.

T2.5-P2 "A Comprehensive Central Asia Seismological Bulletin" details a project to assemble a new comprehensive seismological bulletin for Central Asia that merges the event data from the networks of Kyrgyzstan, Tajikistan and Kazakhstan into a single database, with the aim to improve nuclear test monitoring and verification and promote wider civil and scientific application of test ban relevant data.

T2.5-P3 "Detectability of the UNE Wigwam by Radionuclide Stations of Today's IMS" is an initial investigation of the ability of the IMS radionuclide network to detect underwater nuclear explosions utilizing historic data from Wigwam, the deepest UNE conducted by the United States of America.

***T2.5-P4** "Digitization of Soviet Era Peaceful Nuclear Explosion Seismograms from Regional Stations" presents the peaceful nuclear explosion database, which was created by digitizing analogue seismograms and serves as an excellent data source for crustal studies.

T2.5-P6 "Discrimination of Nuclear Explosions and Earthquakes at Regional Distances for the Lop Nor Test Site According to the KNET Network Data" performs a comparative analysis of the waveforms

of underground nuclear explosions conducted at regional distances at the Lop Nor Nuclear Test Base in China in 1975-1996 as well as tectonic earthquakes from 1991-2018 with epicentres located near the test site and investigates the spectral ratios of the longitudinal and shear wave amplitudes (Sn/Pn, Lg/Pg) of underground nuclear explosions and earthquakes.

T2.5-P7 "Historical Records of Nuclear Explosions in Archives of the Institute of Geophysical Research" describes the archive of nuclear explosion seismograms and other related events available at the Institute of Geophysical Research in Kazakhstan that can be used for nuclear monitoring tasks.

***T2.5-P8** "New Stage of Works on Nuclear Explosions Historical Records Digitization" discusses efforts of the Institute of Geophysical Research in Kazakhstan with the support of other organizations to digitize historical records of nuclear explosions in Central Asia.

***T2.5-P12** "Waveforms from Nuclear Explosions (WFNE)" presents the Waveforms from Nuclear Explosions repository, a very large collection of raw and parametric data on the 2157 nuclear explosions that have been detonated in the world that is available to the research community via an easily accessible web interface.

Theme 3. Verification Technologies and Technique Application

This theme focuses on the systems used for the monitoring of nuclear explosions and the processing of the recorded data. 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. Diverse sources of remotely sensed data, whether from satellites, aircraft or remotely controlled measurement platforms, may find use in nuclear explosion monitoring. OSIs pose special challenges for sensors and associated equipment, which must be capable of detecting observables related to an event that triggered an OSI, especially those related to a nuclear test.

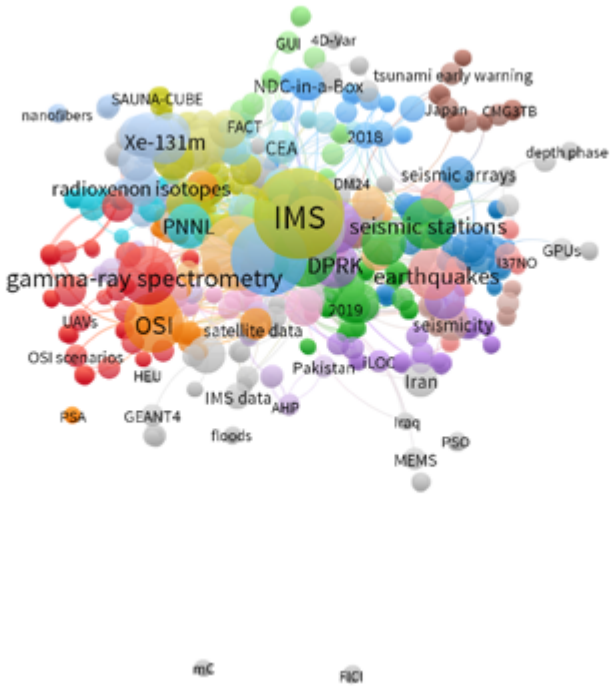


Figure 23. Theme 3. Network visualization by keywords based on the Book of Abstracts (175 abstracts, 764 keywords, 30 clusters). CTBTO Library developed this figure using Mendeley and VOSviewer Software[3].

T3.1 Design of Sensor Systems and Advanced Sensor Technologies

Highlights

Developments in noble gas monitoring promise increased performance and reliability. For example, research projects have identified and characterized new sorption materials, such as metal-organic frameworks, which promise improved collection properties for noble gases, as noted in *Exploiting the Tailorable Nanoporosity of Metal-Organic Frameworks for In-Situ Identification of Radioisotopes* (**T3.1-04**), *Experimental Setup and Results of Xenon Sorption Characteristics Research for a Number of Adsorbents* (**T3.1-P18**), *Investigating New Detection*

[3]The size of the bubble corresponds to the number of abstracts that mention the specific keyword in the Book of Abstracts of SnT2019.
The clusters are represented by colours. They are related to which keyword belongs in co-ocurrency. The bubbles in grey represent isolated keywords. Lines between bubbles represent connections between keywords. The distance between two bubbles indicates the relatedness of both in terms of frequency. The closer two keywords are located to each other, the stronger their relatedness.

Mediums for Atmospheric Radioxenon Measurements (**T3.1-P25**), *Radioxenon Collection Using Synthetized Xenon-Adsorbing Material for Nuclear Test Monitoring* (**T3.1-P32**) and *Study of Materials for Improved Adsorption of Xenon at IMS Radionuclide Stations* (**T3.1-P38**).

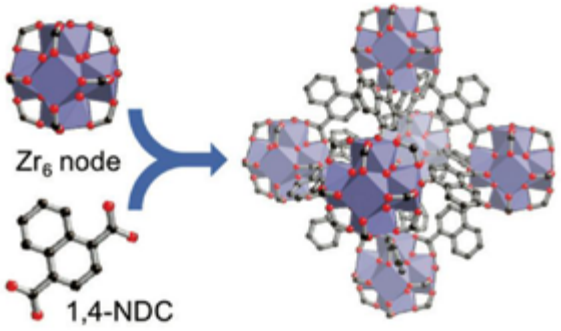


Figure 24. Zr(NDC) scintillating metal-organic framework for adsorbing and detecting radioxenon. From M. D. Allendorf et al. (T3.1-04). Adapted from T. C. Wang, et al (2019). Get the light out: nanoscaling MOFs for luminescence sensing and optical applications. ChemComm 55, 4647. The Royal Society of Chemistry.

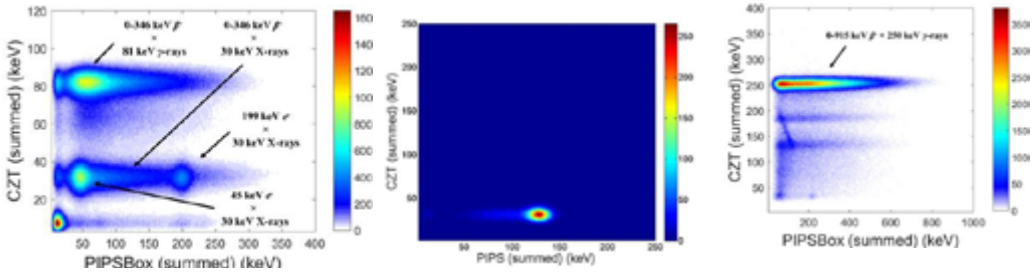


Figure 25. Detection of radioxenon isotopes using a passivated, implanted, planar silicon - cadmium zinc telluride detector. From A. Farsoni et al. (T3.1-P25).

New detectors have shown improved performance in terms of sensitivity or nuclide separation. Several next-generation xenon measurement systems are close to deployment and undergoing acceptance testing, as highlighted in *Report on SPALAX-NG Validation Tests and Performances* (**T3.1-P33**), *Results from a 6-Month Acceptance Test of the SAUNA III - Prototype* (**T3.1-P34**) and *SAUNA-CUBE: The First Prototype for a Noble Gas System Adapted for an Array-Network* (**T3.1-P35**), while others are starting this process, as detailed in *Xenon International* (**T3.1-P49**).

Significant efforts were made by the expert metrology community to better characterize infrasound sensor performance in laboratory and operational conditions, as shown in *Calibration of Infrasound Sensors in a Long-Term Field Study* (**T3.1-P9**), *Status of Infrasound and Seismic Metrology at CEA* (**T3.1-P36**) and *Updated Results from Long-Term Infrasound Sensor Comparison* (**T3.1-P48**).

In addition, the presentation *Description and Results from a Feedback Digital Infrasound Detector System* (**T3.1-01**) described the use of feedback loops within infrasound sensors, which could further increase sensor passband and ease the adjustment of sensor sensitivity.

Presentations *Using the Existing Telecommunication Optical Fiber Cables as Underwater Seismic Events Detectors* (**T3.1-010**) and *Distributed Fiber Optic Seismic Sensors with Seismic Noise Floor Performance* (**T3.1-P17**) presented new studies on the use of existing surface and underwater fibre optic telecommunications cables to detect seismic waves by observing changes to backscattered light. The technology promises interesting civil and scientific applications. Some of these systems appear to have the capability to resolve the seismic low noise model in some parts of the passband monitored for Treaty verification. Developments in this technology should be monitored in the coming years.

Capability in the analysis of noble gases, including natural fission products and activation products, to confirm an underground test explosion has increased. To this end, it is critical to understand the transport of noble gases through the ground to the surface. Presentation *High Throughput Argon-37 Field System* (**T3.1-06**) describes a ^{37}Ar measurement system that has been developed for use in the field and tested. In the OSI context, measurement capability of ^{37}Ar is of particular interest.

A very large number of antineutrinos are produced in a nuclear explosion and travel very large distances through the earth. In theory, the detection of antineutrinos could be used as a proof that a nuclear explosion has occurred. In practice, however, the size of an antineutrino detector required to reliably detect nuclear test poses a practical limitation. *Estimation of Antineutrino Registration as a Method of Monitoring Nuclear Explosions* (**T3.1-03**),

Seismically Cued Antineutrino Detectors Have Limited Potential to Monitor Nuclear Explosions (**T3.1-08**) and *Antineutrino Detectors: An Evaluation of Their Use for Monitoring of Nuclear Explosions* (**T3.1-P5**) present studies that investigate whether antineutrinos emitted from a nuclear explosion can be detected at distance. The findings overall indicated that global monitoring is not possible owing to size and cost constraints. While site monitoring would be feasible in principle, the cost would be prohibitive in comparison with other monitoring technologies.

Presentation *The Feasibility of Using MEMS Technology for Monitoring Large Earthquakes* (**T3.1-09**) describes the use of microelectromechanical systems (MEMS) technology for seismic monitoring. This is an interesting approach with potential civil applications, but the technology is not yet sensitive enough for Treaty verification purposes.

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

***T3.1-01** "Description and Results from a Feedback Digital Infrasound Detector System" presents a low-noise digital infrasound system with an improved calibration method that eliminates the response to seismic signals, thereby providing stable and highly accurate detection capacity.

T3.1-02 "Establishment of a Network of Political and Scientific Cooperation Between CTBTO and the Great Lakes Region to Contribute to Sustainable Development" attempts to contribute to the extension of the CTBTO network and the discussion about regional development and diplomacy.

***T3.1-03** "Estimation of Antineutrino Registration as a Method of Monitoring Nuclear Explosions" presents a new method that will contribute to the prevention of nuclear weapon proliferation and facilitate the process of disarmament, thereby supporting the implementation of United Nations Sustainable Development Goals 16 and 17 and the maintenance of international peace and security.

***T3.1-04** "Exploiting the Tailorable Nanoporosity of Metal-Organic Frameworks for In-Situ Identification of Radioisotopes" describes a new class of sorbents and a novel system architecture for detecting signatures of nuclear detonations over much shorter times than with conventional sorbents, thereby dramatically increasing the timeliness and information content of CTBT verification systems.

T3.1-05 "High Sensitive Xe Measurements" proposes a technology that can significantly improve the performance and sensitivity of the IMS noble gas network.

***T3.1-06** "High Throughput Argon-37 Field System" presents a field system designed for nuclear test monitoring and Treaty verification that accepts air in a variety of forms and measures ^{37}Ar generated from neutron activation of Ca in the soil.

T3.1-07 "How Useful Are (Quantum Technology) Gravity Measurements for On-Site Inspection?" examines the use of more advanced and accurate gravity sensors based on quantum technology that may improve the detection of subsurface features of OSI relevance, such as tunnels and blast chambers.

***T3.1-08** "Seismically Cued Antineutrino Detectors Have Limited Potential to Monitor Nuclear Explosions" concludes that the possibility of using antineutrino detectors to determine whether a detected seismic event is nuclear in nature has limited potential.

***T3.1-09** "The Feasibility of Using MEMS Technology for Monitoring Large Earthquakes" shows that microelectromechanical systems (MEMS) technology is a feasible tool for monitoring seismic events and could help to improve the verification regime of the Treaty.

***T3.1-010** "Using the Existing Telecommunication Optical Fiber Cables as Underwater Seismic Events Detectors" discusses the potential use of existing telecommunications cables in combination with state of the art frequency metrology techniques to detect seismic events.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T3.1-P1 "A Differential Highly Sensitivity Sensor for Accounting of Seismic Devices Instrumental Thermal Noise" suggests using adaptive and optimal filtering of seismic signals based on high precision temperature recording of key elements of seismic instruments, including the use of a highly sensitive thermometer capable of recording the temperature with an accuracy of up to 0.005°C.

T3.1-P3 "A New Process Design for Compact Radioxenon Separation System" presents an enhancement of the SPALAX noble gas system that is being tested, comprising a zeolite absorbent that can directly separate xenon from air without any nitrogen membranes, thus providing a limited working pressure and energy requirement.

***T3.1-P5** "Antineutrino Detectors: An Evaluation of Their Use for Monitoring of Nuclear Explosions" concludes that the application of this technology is not feasible for the IMS.

T3.1-P6 "Application of Optimal Filtering to Take into Account the Influence of Baric and Temperature Fluctuations of the Seismic Instrument and the Environment" shows how the application of optimal filters to correct long-period seismic measurements can significantly improve the final signal to noise ratio and the threshold of detected seismic events.

T3.1-P7 "Applying an Anti-Coincidence System Plastic-HPGe to Lower the MDA of Radioxenon Measurement" presents an anticoincidence system that has been developed by the noble gas laboratory of the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) for the measurement of radioxenon isotopes in atmospheric samples and which shows a reduction of the Compton continuum resulting in decreased minimum detectable activity for all radioxenon isotopes.

***T3.1-P9** "Calibration of Infrasound Sensors in a Long-Term Field Study" argues that a long term comparison of sensor performance can help in determining the stability of a sensor over time, in turn yielding better uncertainty estimates and increasing confidence in the measurements of the monitoring system.

T3.1-P10 "Characterization of the Microbarometer's Sensitivity to the Environment" presents microbarometers developed by the French Alternative Energies and Atomic Energy Commission (CEA) to measure infrasonic waves in the atmosphere and tests carried out to characterize sensors and validate their requirements.

T3.1-P12 "Deployment of Portable Infrasound Array in Costa Rica" discusses the importance of permanent or portable infrasound monitoring systems for volcanic and seismic monitoring of the Latin America and the Caribbean region.

T3.1-P14 "Development of a Mobile Radiation Detection System" presents the highly sensitive AT6103 mobile radiation detection system developed by ATOMTEX SPE of Belarus, which can be used for radiation scanning on land to locate nuclear incidents and to search for orphan sources as well as for analysis of areal contamination after radiation accidents.

T3.1-P15 "Development of a New Compact Photon/Electron Detector for Radioxenon Measurement" presents and discusses the performance of a new lightweight unshielded spectrometer for detection and analysis of atmospheric radioxenon.

T3.1-P16 "Development of an Electrostatic Precipitator System for Radionuclide Particle Collection" provides a new solution for radionuclide aerosol collection that improves nuclear test monitoring capabilities.

T3.1-P17 "Distributed Fiber Optic Seismic Sensors with Seismic Noise Floor Performance" introduces a novel but mature technical approach with the potential to vastly extend the reach of current sensor networks at a low cost and performance that meets or surpasses conventional technical approaches.

***T3.1-P18** "Experimental Setup and Results of Xenon Sorption Characteristics Research for a Number of Adsorbents" presents a technology to evaluate xenon sorbents characteristics that allows the determination of sorbents with required quality at the stages of development and further maintenance of equipment for xenon monitoring.

T3.1-P20 "Future of Aerosol Radionuclide Monitoring" presents a next-generation concept for aerosol radionuclide monitoring developed by a diverse research team in the United States of America that offers upgraded capabilities and less reliance on continuous power, as well as an accidental discovery of a better way to run existing IMS aerosol systems.

T3.1-P22 "Hyper-Sensitive Gamma Spectrometry – Approaching the Ultimate Limit" describes the future potential of gamma spectrometry and the latest developments at radionuclide laboratory RL15 (United Kingdom), the first laboratory to develop a coincidence based gamma spectrometer for CTBT measurements, which has increased detection sensitivity by orders of magnitude.

***T3.1-P25** "Investigating New Detection Mediums for Atmospheric Radioxenon Measurements" presents current technical challenges in radioxenon detection systems and the benefits of using new detection mediums for radioxenon measurements.

T3.1-P27 "Next Generation Low-Power HPGe Gamma-Ray Spectrometer to Improve IMS Particulate Radionuclide Station Reliability" presents a high efficiency (140%) high purity germanium (HPGe) detector developed by the Lawrence Livermore National Laboratory (LLNL) and discusses the current state of HPGe systems, their operational characteristics and possible applications to the IMS.

T3.1-P28 "Project PIM: A Low-Cost Mobile Seismo-Acoustic Sensor for Geophysical Deployments" presents the Pressure and Initial Measurement (PIM) project, the goal of which is to develop a low cost measurement board with multiple seismoacoustic digital sensors and to compare it with existing high fidelity equipment.

T3.1-P30 "Radiation Detection for OSI - A Study of Non-He-3 Neutron Detectors" presents developments in the field of radiation detection and offers new possibilities for radiation safety and the localization of radiation hot spots.

T3.1-P31 "Radioactive Gas Metrology at NPL and the Development of Short-Lived Gas Standards" presents an overview of the capability of the National Physical Laboratory (NPL) in the areas of radioactive gas measurement and radioactivity-in-air monitoring, including planned intercomparison of ^{133}Xe and recent work to produce and standardize the short lived fission and activation product gases ^{41}Ar, ^{85m}Kr, ^{87}Kr, ^{88}Kr and ^{135}Xe for the calibration of a criticality monitor at the Fukushima Daiichi Nuclear Power Plant.

***T3.1-P32** "Radioxenon Collection Using Synthetized Xenon-Adsorbing Material for Nuclear Test Monitoring" discusses the current state of metal-organic framework material for collecting radioactive xenon isotopes from atmospheric raw air for applications in the context of nuclear test monitoring, its characterization, system modelling and possible applications of relevance to the CTBT.

***T3.1-P33** "Report on SPALAX-NG Validation Tests and Performances" reports on validation tests of SPALAX noble gas monitoring equipment, which demonstrated outstanding performance for detection limits for the four relevant radioxenon isotopes and the ability to separate unambiguously the contribution of each isotope.

***T3.1-P34** "Results from a 6-Month Acceptance Test of the SAUNA III - Prototype" presents results from testing of the SAUNA III prototype over a six month evaluation period by the Swedish Defence Research Agency (FOI) in cooperation with the CTBTO.

T3.1-P35 "SAUNA-CUBE: The First Prototype for a Noble Gas System Adapted for an Array-Network" presents the design and functionality of SAUNA-CUBE, the first industrial prototype of a noble gas system for an array network, as well as initial test results and further plans.

***T3.1-P36** "Status of Infrasound and Seismic Metrology at CEA" focuses on the low frequency dynamic environmental metrology activities of the French Alternative Energies and Atomic Energy Commission (CEA) at its new measurement and testing facilities dedicated to infrasound and seismic sensors, as well as its research and development work in metrology.

T3.1-P37 "Status of the Stack Monitor for the STAX project" presents the manufacturing status of the stack monitor for the Source Term Analysis of Xenon (STAX) project of INVAP, in particular the hardware, the status of development of the measuring chamber, and shielding and sampling systems.

***(T3.1-P38** "Study of Materials for Improved Adsorption of Xenon at IMS Radionuclide Stations" presents a fundamental study of xenon adsorption materials (activated carbons, silver doped zeolites, metal-organic frameworks) for more efficient noble gas monitoring at IMS stations, which could result in lower detection limits or shorter collection and processing times, as well as the first results of the study.

T3.1-P39 "Testing of Cosmic Veto for RASA Background and MDC Reduction" presents tests of a commercially available cosmic background reduction system for its potential to improve the sensitivity of the Radionuclide Aerosol Sampler and Analyzer (RASA) automatic radionuclide particulate detection system.

T3.1-P41 "The Gas Processing System of SAUNA CUBE" presents and evaluates the performance of the first prototype radioxenon system of SAUNA CUBE, which is smaller and less complex than the systems currently used in the IMS.

T3.1-P42 "The Güralp Affinity as a Replacement for the DM24SxAM" presents the design concept of the Affinity digitizer and compares it with the long running DM24-based digitizer products that are currently in use, and recommends the Affinity as a drop-in replacement.

T3.1-P43 "The Radiation Dose Monitoring Network System in a Coastal Area" presents a study on a radiation monitoring network for radiation protection purposes.

T3.1-P44 "Three Future Filters for IMS Radionuclide Particulate Operations" describes preparations of the CTBTO for the testing and qualification of IMS filter materials in order to manage and ensure the future supply of filter media needed to sustain longer term IMS radionuclide particulate sampling.

T3.1-P45 "Towards Disaster Mitigation on Earthquakes and Tsunamis Using Off Shore Real Time Monitoring Data" explains the integration of real time data and advanced simulation for early detection of earthquakes and tsunamis.

T3.1-P46 "Ultra-Sensitive Measurements of Large-Volume Radioxenon Samples Using an Ultra-Low-Background Proportional Counter" looks at the potential of using very large volume radioxenon samples to achieve significant improvements in sensitivity to more accurately characterize regional radioxenon backgrounds.

T3.1-P47 "Unmanned Aerial Vehicles in On-Site Inspection: New Techniques for Gamma Spectroscopy Survey" argues that the inclusion of directional sensing and unmanned aerial vehicles in gamma spectroscopy surveys can enhance OSI capabilities.

***T3.1-P48** "Updated Results from Long-Term Infrasound Sensor Comparison" presents updated results from ongoing testing of infrasound sensors and discusses potential sources of response variability and how they may affect station performance.

***T3.1-P49** "Xenon International" presents a highly reliable instrument for the detection of radioxenon isotopes that has twice the sensitivity and speed of the instrument that is currently deployed in the IMS.

T3.2 Laboratories Including Mobile and Field Based Facilities

Highlights

In this session, three areas of noble gas laboratory technology innovation were indicated: (1) ^{37}Ar analysis for OSI laboratory, (2) further reducing background in IMS particulate laboratories such as the gamma–gamma coincidence technique and (3) enhancing noble gas analysis capability by increasing sample throughput at IMS laboratories, as well as increasing sensitivity.

Presentation *Investigations of the Characteristics of Installation for the Measurement of Low Activities of Ar-37 Based on the Detection of Liquid Argon Scintillation* (**T3.2-01**) concerned challenges in using liquid scintillation technology to analyse ^{37}Ar, which is an important noble gas for the OSI laboratory. In this method, the argon gas needs to be liquefied, whereas the current CTBT/OSI technology measures argon gas with a proportional counter. Liquid scintillation technology would require the same amount of argon as proportional counters but possibly enable a significant reduction in the detection limit of ^{37}Ar.

Presentation *More Sensitive Measurements that Radionuclide Laboratories Can Do for Special Studies* (**T3.2-02**) presented the option of particulate laboratory technology innovation for reducing the background and proposed the gamma–gamma coincidence technique in addition to cosmic veto shields and low background material. These advanced systems have the potential for far greater detection capability.

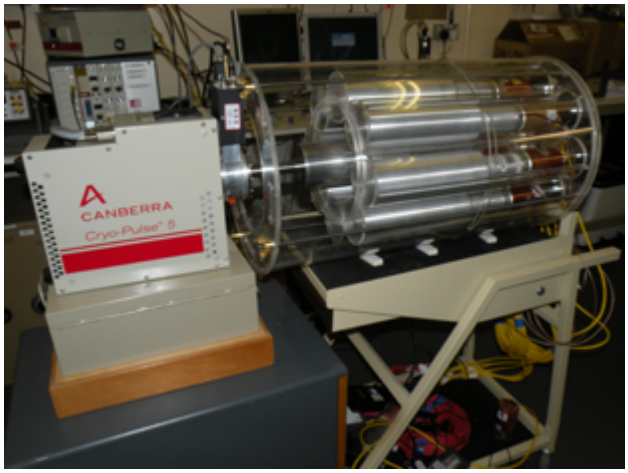


Figure 26. Monitoring Facilities: Multi-detector configuration for Compton suppression gamma spectrometry at a radionuclide laboratory for special studies. From A. Davies et al. (T3.2-02).

Presentation *Sample Throughput Improvements for the U.S. Noble Gas* (**T3.2-03**) focused on enhancing noble gas measurement capability at IMS laboratories by increasing sample throughput with four additional detectors and showed that even though this requires more complex system control, the additional detectors have improved energy resolution.

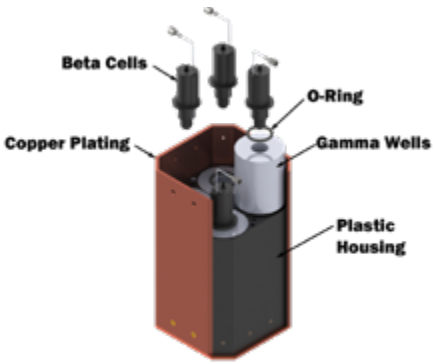


Figure 27. Quad detector setup to achieve higher throughput at USL 16 noble gas laboratory. From M. Foxe et al. (T3.2-03).

In this session, three areas of noble gas laboratory technology innovation were indicated: (1) ^{37}Ar analysis for OSI laboratory, (2) further reducing background in IMS particulate laboratories such as the gamma–gamma coincidence technique and (3) enhancing noble gas analysis capability by increasing sample throughput at IMS laboratories, as well as increasing sensitivity.

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

***T3.2-01** "Investigations of the Characteristics of Installation for the Measurement of low Activities of ^{37}Ar Based on the Detection of Liquid Argon Scintillation" presents an installation for the detection of ^{37}Ar based on the liquid scintillation principle that significantly reduces the detection limits of ^{37}Ar.

***T3.2-02** "More Sensitive Measurements that Radionuclide Laboratories Can Do for Special Studies" presents prototype next-generation gamma spectrometry systems being developed through ongoing collaboration between Pacific Northwest National Laboratory (PNNL) and AWE Aldermaston that can improve sensitivity by two to four orders of magnitude, allowing unprecedented detection of radionuclides and an enhanced verification regime.

***T3.2-03** "Sample Throughput Improvements for the U.S. Noble Gas Laboratory" details the operational enhancements to the noble gas system at radionuclide laboratory RL16 (United States of America) and the importance relative to the capabilities of CTBTO.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T3.2-P1 "Accuracy of Particulate Sample Analysis with a BEGe Detector" focuses on equipment used by radionuclide laboratories, provides insight into what happens after an event has occurred and presents analysis algorithms used to screen an event.

T3.2-P2 "Developing a Laboratory-Based Beta-Gamma Coincidence Detection System" presents progress made by IMS radionuclide laboratory RL15 (United Kingdom) in the development of a new, laboratory based beta–gamma coincidence detection system for the measurement of noble gases or particulate radionuclides in environmental samples.

T3.2-P4 "Efficiency of Ion Exchange Columns for Precipitation Sampling" investigates the collection efficiency of the ion exchange columns and the effects of ashing at different temperatures and performs tests of a new ion exchange resin.

T3.2-P5 "Further Development of the SAUNA-FIELD System for Rapid Deployment and Improved Operation" describes a new improved functionality for the measurement of the noble gas xenon during an OSI that reduces the inspector workload and increases measurement capacity.

T3.2-P7 "Radioxenon Spiked Air for Field Testing" adds to the already robust measurements taking place and will contribute to an even more reliable and trusted system of quality diagnostic xenon measurement and verification.

T3.2-P9 "Status and Results of Xenon Proficiency Test Exercises" presents the xenon proficiency test exercises, a key part of the laboratory quality assurance/quality control programme that supports the CTBTO review of laboratory capabilities and compliance.

T3.3 Remote Sensing, Satellite Imagery and Data Acquisition Platforms

Highlights

Presentation *Continuous and Unattended Spectroscopic Operation and Analysis with the Mirion Data Analyst* (**T3.3-01**) focused on a system to support gamma radiation spectral measurements and covered a range of different applications, including the use of detectors on unmanned aerial vehicles as well as laboratory spectral equipment.

Presentation *International Radiation Monitoring Information System (IRMIS)* (**T3.3-02**) introduced a geographical information system to share spatial information in the context of nuclear emergencies. The presenter highlighted the problem of data being provided in different formats and the need to simplify and standardize data input.

Posters covered a broad range of data acquisition systems that included the application of multispectral remote sensing from space (**T3.3-P4**, **T3.3-P5**) and airborne (**T3.3-P10**) platforms. This extended to the use of a physical airborne simulator to support the testing and training needs of OSI (**T3.3-P7**). Innovative methods for supporting various aspects of an OSI were also presented (**T3.3-P11**).

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

***T3.3-01** "Continuous and Unattended Spectroscopic Operation and Analysis with the Mirion Data Analyst" presents a device that allows unattended operation of gamma spectroscopy systems, making remote laboratory locations more viable.

***T3.3-02** "International Radiation Monitoring Information System (IRMIS)" presents IRMIS, a web application of the Incident and Emergency Centre of the International Atomic Energy Agency that shares international radiation monitoring maps during nuclear or radiological emergencies in order to contribute to public protection.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

***T3.3-P4** "Applying Multispectral and Hyperspectral Imagery Analysis to Monitor and Verify Front-End Uranium Production" argues that emerging remote sensing technologies can increase transparency into States that may be ramping up uranium production for weapons purposes and thereby prevent the acquisition or production of fissile material.

***T3.3-P5** "Comparison of Satellite Earth Observation and Seismic Data to Analysis the Effect of Nuclear Tests in 2017 North Korea" uses satellite earth observation data to develop change detection techniques to support OSI.

***T3.3-P7** "Design and Construction of an OSI Airborne Techniques Simulator" presents an airborne techniques simulator that has been constructed to support the training of surrogate inspectors and testing of OSI airborne equipment.

T3.3-P8 "Improvements to the Standard Station Interface (SSI) Software: State of Health and Authentication with ECDSA" presents modifications made to the state of health module of the standard station interface (SSI) software in order to provide station operators a means to access state of health information, such as meaningful measurements provided by the digitizers, SSI and supporting equipment, and to perform authentication with the elliptic curve digital signature algorithm (ECDSA).

T3.3-P10 "Potential Ways for Optimization of Multispectral Including Infrared (MSIR) Imaging for On-Site Inspection (OSI)" investigates potential ways to optimize airborne multispectral including infrared imaging equipment and demonstrates the value of data gathered by such sensors for ground-truthed areas.

***T3.3-P11** "Several Key COTS Equipment's Potential Application to CTBTO OSI" introduces commercial off the shelf (COTS) equipment that could strengthen OSI capability and also promote more social awareness of the CTBT.

T3.4 Augmented Reality and Fusion of Data from Different Monitoring Technologies

Highlights

Presentation *Recreating and Exploring the DPRK Nuclear Test Site in 3D to Calculate Possible Overburdens for Detonations* (**T3.4-01**) explained the methodology to reconstruct the geographical information on test sites in the Democratic People's Republic of Korea and to present it using augmented reality technology, based on information provided by the Democratic People's Republic of Korea, satellite imagery such as Google Earth, and elevation information as well as the epicentres of nuclear explosions with confidence ellipses. The presentation concluded that there is good agreement between the announced information and reconstructed data. Considering the mission of the CTBTO, the direct application of the developed method could be for OSI. With this technology, the inspection team can comprehend the geographical information intuitively and may conduct the inspection more smoothly.

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

***T3.4-01** "Recreating and Exploring the DPRK Nuclear Test Site in 3D to Calculate Possible Overburdens for Detonations" uses 3-D visualizations to improve data analysis methods and to facilitate understanding by non-specialists of methods and results in order to gain a greater understanding of the nuclear test site in the Democratic People's Republic of Korea and the location of the tests.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T3.4-P1 "Data Fusion of Electromagnetic and Infrasound Measurements" presents experimental and theoretical results on how fusing electromagnetic signals with infrasonic records can be used to identify and filter out lightning signals to avoid false identification as a nuclear explosion.

T3.4-P2 "Detection and Interpretation of Explosive Events by Seismic and Infrasound Networks of Ukraine" presents the National Data Centre in Ukraine, suggests ways to improve monitoring at the regional level, including through the use of satellite data, and discusses possible civilian applications of monitoring technologies to emergency situations.

T3.4-P3 "Detection and Location of an Earthquake Using Seismic, Infrasound and Hydroacoustic Data: A Case Study of Botswana" analyses data collected in Botswana using graphical user interface for progressive multichannel correlation (GPMCC) software by methods of spectrum, azimuth and correlation between the acoustic and seismic signals for phase, magnitude, time and slowness and shows that the foreshocks and aftershocks of the strong earthquake on 3 April 2017 were detected by the seismic, hydroacoustic and infrasound stations.

T3.5 Data Analysis Algorithms, Artificial Intelligence, Big Data and Deep Learning

Highlights

Several presentations highlighted the application of machine learning to improve resolution and the statistical power of screening and discrimination in both waveform and radionuclide processing. The most significant achievement of machine learning in the past decade is the implementation of the event building methodology of NET-VISA in the IDC operational system as described in *The Machine-Learning Tool NET-VISA from Cradle to Adulthood - The Next Generation System of the IDC and the SnT Process* (**T3.5-014**).

NET-VISA: Evaluation of Event Location Performance Compared to SEL3, and NEIC PDE (**T3.5-010**) demonstrated the increase in accuracy of event location achieved by NET-VISA. Machine learning has also become a useful tool for significant improvements in the fast travel time calculation in various 3-D earth models, as described in *Machine Learning for Emulation of Seismic-Phase Travel Times in 3-D Earth Models* (**T3.5-09**).

Presentation *Identification of Repeating Seismic Events Using Diffusion Maps* (**T3.5-07**) demonstrated how advanced machine learning techniques such as diffusion maps allow for more reliable automatic identification of repeating seismic events. The presentations *Machine Learning to Categorize Radionuclide Spectra* (**T3.5-016**) and *Automatic Machine Learning Methods for Analyzing Radioxenon Isotopes Spectra* (**T3.5-P13**) explored how machine learning can be directly applied to radionuclide spectra.

Can High-Precision Methods of Seismic Monitoring for Earthquakes and Explosions Find Application for Broad Areas? (**T3.5-04**) and *Continuous Assessing of the Reviewed Event Bulletin with Waveform Cross Correlation* (**T3.5-05**) presented how new methods of event location based on waveform cross-correlation (WCC) can improve the accuracy of absolute location by two orders of magnitude, even for events that are much smaller than those in the Reviewed Event Bulletin. The number of found seismic events may grow by an order of magnitude with detection techniques using WCC. Most of these events do not match the IDC event definition criteria.

Presentations *Can High-Precision Methods of Seismic Monitoring for Earthquakes and Explosions Find Application for Broad Areas?* (**T3.5-04**) and *Recent Improvements on the Broadband Seismic Network of Iran (Implementing Tuned Seiscomp3 and Automatic Online Moment Tensor Inversion)* (**T3.5-012**) focused on improvements in seismic monitoring and analysis. Significant scientific/technical expertise, computational power and archived data from global, regional, and local networks of digital seismometers should be integrated in data processing in the next 10 to 20 years to retrieve and analyse full information from seismic events. The spot check tool based on cross-correlation is an important step towards accurate location of seismic events and better understanding/characterization of the global distribution of natural seismicity. It also serves as a tool to identify on global and regional scale events similar to the numerous historical underground nuclear tests.

The poster *Improvements of Phase Detection and Identification Using 3C Array Processing* (**T3.5-P35**) makes the case that three-component (3-C) seismic arrays offer the possibility to use the coherency of the horizontal components to improve the detection and the characterization of the S phases that have a greater amplitude on the horizontal component than on the vertical one. The authors point out that 3-C arrays are currently poorly exploited and propose using them for automatic S phase detection, classification and identification algorithm.

The IDC presentation *Statistical Analysis to Advance Common Understanding on SAUNA False Positives Hypothesis* (**T3.5-013**) compiled results of the new configuration of the net count calculation method that show a satisfactory reduction in the rate of false positives after dropping the binary condition on interference corrections. A recommendation was made to promote the new configuration into IDC operational radionuclide

software for noble gas analysis. Results from the Swedish Defence Research Agency (FOI) using Monte Carlo data corroborated IDC findings.

Participants also welcomed the progress achieved by the IDC as presented in *Unified Implementation of NCC Analysis Algorithms for Both Current and Next Generation Beta-Gamma Coincidence Based Noble Gas Systems* (**T3.5-015**) with the new software autoSTRADA (Automatic Software Tool for Radionuclide Data) for current and next-generation noble gas systems and expressed a great interest in the software.

Two posters on an objective Bayesian computation framework, *Source Term Estimation in the Presence of Nuisance Signals* (**T3.5-P62**) and *Source Term Estimation Using Multiple Isotopes in Atmospheric Samples* (**T3.5-P63**) were presented by Pacific Northwest National Laboratory. This method uses certain free parameters to create a model of background and signal through optimization. The results provide probable values for source magnitude, release time, and release location. The new developments reported here are including multiple sources and differen release patterns over time. The isotopic ratios are used to discriminate between various source types.

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

T3.5-01 "A Methodology to Establish Bayesian Detection Limits for Radionuclide Monitoring" presents a methodology for IMS noble gas data to obtain reliable detection limits and false positive rates when processing faint signs of nuclear testing.

T3.5-02 "A Semi-Automatic Method for Cepstral Depth Estimates for Sequences of Shallow Events" describes a semiautomatic cepstral method for estimating the depth of very shallow earthquakes and explosions.

***T3.5-04** "Can High-Precision Methods of Seismic Monitoring for Earthquakes and Explosions Find Application for Broad Areas?" evaluates the greatly improved capability to manage vast numbers of signals when discriminating nuclear explosions from natural earthquakes and chemical blasts and discusses how these methods can be used to help cope with the many non-nuclear signals.

***T3.5-05** "Continuous Assessing of the Reviewed Event Bulletin with Waveform Cross Correlation" applies waveform cross-correlation to assess the similarity between the reviewed events in the IDC database and new arrivals associated with Reviewed Event Bulletin events, thus assessing the quality and completeness of the bulletin.

***T3.5-07** "Identification of Repeating Seismic Events Using Diffusion Maps" applies diffusion maps, an advanced machine learning technique, for the automatic identification of repeating seismic event clusters such as aftershock sequences.

***T3.5-09** "Machine Learning for Emulation of Seismic-Phase Travel Times in 3-D Earth Models" shows how machine learning efficiently emulates travel time calculations, opening the possibility of using state of the art 3-D earth models in the operational system to improve seismic travel time prediction and event location accuracy.

***T3.5-010** "NET-VISA: Evaluation of Event Location Performance Compared to SEL3, and NEIC PDE" evaluates the performance of the NET-VISA software that will perform the automatic association and location steps in the next-generation IDC software, in terms of the completeness of automatic events and location accuracy.

T3.5-011 "Peak Identification in EDS Measurements Using Multiple Subset Sum Problem Formulation" discusses peak identification using the matching of unidentified or cumulated peaks with adequate nuclides during particulate spectrum analysis of IMS stations.

***T3.5-012** "Recent Improvements on the Broadband Seismic Network of Iran (Implementing Tuned Seiscomp3 and Automatic Online Moment Tensor Inversion)" demonstrates how big data automatic analysis and online processing for event identification and detection with source mechanisms has led to fully automatic processing of real time data.

T3.5-013 "Statistical Analysis to Advance Common Understanding on SAUNA False Positives Hypothesis" presents a retrospective analysis of reported detections indicating that the rate of false positives for some isotopes has been overestimated and compares results from a new configuration of the net count calculation method that systematically performs interference corrections with the standard method.

***T3.5-014** "The Machine-Learning Tool NET-VISA from Cradle to Adulthood - The Next Generation System of the IDC and the SnT Process" presents an example of innovative technology that has benefitted from the interaction between the CTBT community and the scientific community at large, resulting in an operational software product that improves the quality of the Reviewed Event Bulletin.

***T3.5-015** "Unified Implementation of NCC Analysis Algorithms for Both Current and Next Generation Beta-Gamma Coincidence Based Noble Gas Systems" presents the key features of the new unified implementation of net count calculation (NCC) algorithms at the IDC for handling spectral data from both current and next-generation beta–gamma coincidence based noble gas technologies.

***T3.5-016** "Machine Learning to Categorize Radionuclide Spectra" uses convolutional neural networks to automatically categorize radionuclide spectra.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T3.5-P1 "A Demonstration of the RKF Solution Method for Multi-Physics Analysis of Radionuclides Evolved in Nuclear Testing" highlights the importance of extremely flexible, accurate numerical approaches in determining radionuclide source terms.

T3.5-P2 "A New Analysis Method for Beta–Gamma Radioxenon Spectra, Including Improved Calculation of Decision Limits" presents a newly developed method for analysis of beta–gamma coincidence radioxenon spectra that is simpler than the net count calculation method, requires fewer regions of interest, and estimates the decision limits using a Bayesian correction.

T3.5-P3 "A New Approach for Calculating 1D Local Velocity Model Using Particle Swarm Optimization Technique" proposes a new approach for calculating a seismic velocity model that in comparison with classical deterministic methods is more stable, more efficient, easier to use and, by using parallelism capability, faster.

T3.5-P4 "A New Blind Deconvolution Approach for the Separation of Seismic Waves" proposes a new method for calculating a 1-D local seismic velocity model that uses a powerful method in global optimization, the Fuzzy Self-Tuning Particle Swarm Optimization (FST-PSO), and applies it to a calculated 1-D velocity model of the southern part of the Central Alborz mountain range in the Islamic Republic of Iran.

T3.5-P5 "A Novel Approach for Signal Sparse Time-Frequency Representations" exploits the fact that most real-life signals are sparse to apply an algorithm that eliminates the need for threshold value selection by introducing a rule for the adaptive threshold value calculation which results in time–frequency representations free from unwanted interferences.

T3.5-P6 "A Semi-Automatic Method for Extraction and Interpretation of Reflection Green's Functions from Ambient Noise and Signal, for IMS Seismic Station Crustal Reflector Characterization" applies seismic interferometry to extract reflection Green's Functions at primary seismic station PS48 (United States of America), a well-calibrated IMS primary seismic array, and uses a semiautomatic method to extract and characterize the crustal reflector structure beneath the station.

T3.5-P7 "A Simplified Fuzzy ARTMAP Neural Network Based-Approach for Seismic Signal Discrimination Between Earthquakes and Quarry Blasts" proposes an artificial intelligence based scheme for recognition of earthquakes and blasts.

T3.5-P9 "Analysing Seismic Explosion Records Using SEISAN" demonstrates a freely available and easy to use seismic software package that can aid smaller National Data Centres in their verification activities.

T3.5-P11 "Applying Waveform Correlation to Aftershock Sequences Using a Global Sparse Network" presents a method for station and template selection, threshold setting and event detection that is specialized for aftershock processing in a sparse, global network and applies the methods to several aftershock sequences to evaluate the potential for establishing a set of standard aftershock waveform correlation processing methods that can be effective for operational monitoring systems with a sparse network.

T3.5-P12 "Automatic Characterization of Phase Type at Three-Component Seismic Stations Using Neural Networks" focuses on the application of modern machine learning methods to improve automatic processing of data from three-component seismic stations.

***T3.5-P13** "Automatic Machine Learning Methods for Analysing Radioxenon Isotopes Spectra" introduces machine learning methods for automatic analysis and processing of radioxenon isotope spectra and automatic classification of radioxenon events based on their activity and gamma and beta energy.

T3.5-P14 "Automatic Systems for Accurate Tracking of Aftershock Sequences" presents a process for detecting and locating aftershocks automatically, relieving the human analysts and helping ensure that suspicious events are not missed.

T3.5-P15 "Bayesian Approach to Localization of Atmospheric Release with Demonstration on the Case of Ruthenium-106 Release in 2017" studies techniques to localize an unintended atmospheric release of ^{106}Ru and demonstrates that the spatial and temporal distribution of measurements is crucial for localization.

T3.5-P16 "Can Artificial Intelligence Help Detect Nuclear Explosions?" reviews the application of machine learning techniques to improve processing of data from different types of IMS stations.

T3.5-P18 "Comparing REB and SSEB (IDC Products) with Other Seismic Data Centres" compares IDC bulletins with results from other international seismic data centres, focusing on differences

between the results of the Jordan Seismological Observatory and IDC products, and concludes that the differences may be the result of using different analysis algorithms, velocity models or travel time tables.

T3.5-P19 "Comparison of Pick-Based and Waveform-Based Event Detectors for Local to Near-Regional Distance Data from Utah" compares a pick-based seismic event detector to a waveform-based detector on data from three-component stations in the University of Utah network and concludes that when tuned to achieve a comparable level of recall, the waveform based method is more precise and stable and easier to configure.

T3.5-P20 "Contribution of Kazakhstan's Stations of the International Monitoring System into Global and Regional Monitoring" compares the Reviewed Event Bulletin and the bulletins of the National Data Centre of Kazakhstan and finds that the seismic bulletin of Kazakhstan contains a significantly larger number of seismic and infrasound events within Central Asia.

T3.5-P22 "Detecting Low Magnitude Seismic Events Using Convolutional Neural Networks" examines the use of machine learning techniques to improve detection of small, difficult to detect events.

T3.5-P25 "Detection Performance of Dynamic Correlation Processors Using De-Noised Signal Space-Spanning Templates" demonstrates how dynamic correlation processors improve nuclear test monitoring by, in some circumstances, significantly outperforming conventional correlation detectors.

T3.5-P26 "Developing a Deployable, Flexible Radionuclide Analysis Pipeline" shows some of the features of the tools used to interact with the radionuclide data in a flexible system that can be deployed at short notice, as well as the results of a recent National Data Centre collaboration.

T3.5-P28 "Discrimination Between Nuclear Explosions and Natural Earthquakes" applies multiple methods, such as complexity, spectral ratio, amplitude ratio of P/S and mb-Ms, to discriminate between underground nuclear explosions and earthquakes.

T3.5-P29 "Disturbing Incidents Signal Character Analysis in Nuclear Explosion Infrasound Detection" analyses the frequency characteristics of infrasound detections from various incidents like lighting, chemical explosions and satellite launches in order to identify frequency ranges in the power spectrum that can be applied for infrasound detection and identification of signals that may indicate a nuclear explosion.

T3.5-P30 "Dynamic and Agnostic State of Health (SOH) Analysis Tools for Noble Gas Systems" describes recently developed software tools to analyse the state of health of noble gas systems using a modular framework that provides the ability to run multiple algorithms in parallel.

T3.5-P31 "Enhancement on the Algorithm of Characterization Limits of the Net Count Calculation Method for Low Counts of IMS Beta-Gamma Coincidence Noble Gas Samples" presents the results of an enhanced algorithm compared with the current net count calculation method for noble gas beta–gamma coincidence spectra using both real IMS samples as well as synthetic Monte-Carlo generated sample spectra with very low count rates at detector background level.

T3.5-P32 "Exploiting Bayesian Inference Priors to Form Synthetic Waveform Events or to Validate Events Formed by Automatic Processing" uses a machine learning model that has been developed to detect seismic events, to generate high quality seismic events or to validate events formed by another algorithm.

T3.5-P33 "Global and Local Scale High-Resolution Seismic Event Catalogues for Algorithm Development and Testing" presents high resolution seismic event catalogues that provide a resource for nuclear explosion monitoring researchers to develop and objectively test new data processing algorithms to improve nuclear test monitoring and verification.

***T3.5-P35** "Improvements of Phase Detection and Identification Using 3C Array Processing" focuses on the use of horizontal components in the progressive multichannel correlation array processing technique to identify complex seismic wavefield features, to investigate the influence of horizontal trace rotation on the consistency of the array, to perform a series of measurements to precisely establish the orientation of each station and to investigate the influence of station orientation errors on the array consistency.

T3.5-P36 "InfraPy – An Open Source Signal Analysis Toolkit for Infrasound Research" presents an open source signal analysis tool with infrasound support that was developed to facilitate collaboration within the international explosion monitoring community and to provide researchers at the Los Alamos National Laboratory with feedback on algorithm performance.

T3.5-P37 "iNSPIRE: iNtegrated Software Platform for the Interactive REview - The First Release Features for Beta-Gamma Coincidence Based Noble Gas Data" compiles the main features of the first release of the iNtegrated Software Platform for the Interactive REview (iNSPIRE) platform, which offers analysis functionalities for beta–gamma coincidence based noble gas data.

T3.5-P38 "Joint Processing of Seismic and Infrasound Signals from Mining Blasts" demonstrates how the joint automatic processing of seismic and infrasound signals of repeating seismic-acoustic events, based on waveform cross-correlation, enhances the uniqueness of mining blast detection and exemplifies continuous improvement in nuclear test monitoring.

T3.5-P39 "Learning About Small-Scale Atmospheric Structures Through Recurrent Infrasound Events" demonstrates that recurrent well-characterized infrasound events can be used to better constrain regional atmospheric models for each IMS infrasound station.

T3.5-P41 "Long-Term Infrasound Monitoring of Volcanic Activities of Kyushu Region in Japan" analyses infrasonic records using progressive multichannel correlation with a reference to the event origin time of advisory reports, focusing on the Sakurajima eruption, which is most active, and finds that the annual variations of arrival time and back azimuth of infrasound signals are well matched to the annual change of atmospheric conditions on a regional scale and the effects of winter stratospheric sudden warming in 2011/2012 and 2012/2013.

T3.5-P43 "Matrix Operation of the Net Count Calculation Method for Beta-Gamma Coincidence Spectrum Analysis of IMS Noble Gas Samples" discusses the definition of the interference ratio with respect to calculation algorithms and investigates the calculation procedures of the net counts, their uncertainties and critical limits and how the configurations were optimized for samples from the noble gas systems SAUNA II/III, Xenon International and SPALAX NG.

T3.5-P44 "Mel Cepstrum Techniques for Event Identification" uses mel cepstrum coefficients for feature extraction on seismic and infrasound signals and presents preliminary results that suggest that some event categories, such as atmospheric nuclear explosions, have consistent mel cepstra and especially consistent differential mel cepstrum coefficients in neighbouring mel frequency bands.

T3.5-P45 "Multilayer Neural Network Architecture Optimization and Performance Amelioration for Seismic Signal Classification Using Genetic Algorithms" proposes an automatic genetic optimization algorithm for seismic signal classification using the multilayer perceptron neural network to classify seismic data and apply it to real seismic data.

T3.5-P46 "Optimization Algorithm for Synergy of CTBT Verification Techniques in Addressing IMS and OSI Tasks" presents an algorithm for CTBT verification methods synergy that ensures an optimal Neyman-Pearson operating characteristic of nuclear explosion detection based on a set of standard discriminants used in addressing IMS and OSI tasks.

T3.5-P48 "RASA Filter Jam Detection Algorithms" presents a smart algorithm to predict filter jams and stop the filter motor, potentially enabling faster system restoration and reduced downtime using the existing state of health sensor on the RASA automatic radionuclide particulate detection system.

T3.5-P50 "Reduction of Wind Noise Impact Based on the Use of Data from a Weather Station in Recording Infrasound Signals at IS43" presents a method for reducing wind noise impact on the recording of infrasound signals by considering wind speed at IMS infrasound stations and analyses the dependence of false alarms on the detection probability.

T3.5-P51 "RNIAC: A Cloud-Based Approach of the Radionuclide National Data Centre (NDC) in a Box Software (RNIAB)" presents the potential benefits of implementing cloud based solutions for operating the radionuclide NDC in a box software package.

T3.5-P52 "RSTT Validation Studies in the Middle East, Central Asia and the Caucasus" demonstrates that regional seismic travel time (RSTT), a global 3-D velocity model of the crust and upper mantle developed by the Lawrence Livermore National Laboratory, the Los Alamos National Laboratory and Sandia National Laboratories, brings an overall improvement in the location accuracy of seismic events.

T3.5-P53 "Scientific Evaluation of the Benefits of Increase in Resolution for IDC's ATM Tools and Launching Interface" evaluates the generally accepted assumption that guidance resulting from atmospheric transport modelling usually benefits from an increase of spatial and temporal resolution and presents initial results.

T3.5-P54 "SeisComP3 iLoc Integration Applied to Array Processing" extends the graphical user interfaces of the open source SeisComP3 software package to support array processing and presents the array processing results for the nuclear weapons tests of the Democratic People's Republic of Korea and other induced seismic events applying the iLoc seismic event locator in comparison with existing locators such as LocSat.

T3.5-P56 "Seismic Phase Identification with Deep Learning in Frequency Domain" uses the deep learning technique to identify seismic phases in the frequency domain instead of raw time records.

T3.5-P57 "Sensitivity Analysis and Disaggregation of Recent Seismic Hazard Assessment in Egypt" identifies seismic sources and calculates their seismicity parameters using an earthquake catalogue of Egypt and its surroundings from 2200 BC to 2016 AD, two de-clustering algorithms, three seismotectonic models and four ground motion prediction equations.

T3.5-P58 "Sensitivity of a Bayesian Source-Term Estimation Model to Spatiotemporal Sensor Resolution" presents significant improvements to the source term estimation algorithm that extend its applicability to coarser-resolution observational data sets and evaluates the enhanced algorithm in multiple ways.

T3.5-P60 "Simulations of Gamma Ray Spectra of Fission Samples" discusses a gamma ray spectra model of fission samples of varying ages using a combination of Koala code and GEANT4 software, obtained results and possible applications, such as nuclear forensics.

T3.5-P61 "Source Spectral Discrimination Between Shallow Earthquakes and Quarry Explosions in Northern of Egypt" analyses and compares P- and S-wave observed velocity and displacement source spectra from earthquakes and quarry explosions with similar magnitudes and concludes that spectra from quarry explosions decrease more sharply at high frequencies than earthquakes of the same estimated magnitudes, leading to lower corner frequency estimates, and that the earthquake velocity spectra contain high frequency energy compared with the spectrum of the quarry explosions.

***T3.5-P62** "Source Term Estimation in the Presence of Nuisance Signals" presents a multi-isotope analysis approach tested in a synthetic experiment that led to surprising accuracy in source term parameter estimation, using a scenario that included a prompt release from an underground nuclear explosion and recurring nuisance releases.

***T3.5-P63** "Source Term Estimation Using Multiple Isotopes in Atmospheric Samples" presents a computation that estimates the source type of isotopes in an IMS radionuclide event, objectively screening out civilian radionuclide events that only work when multiple isotopes are detected.

T3.5-P65 "Spectral Region-of-Interest Methods Used in Net Count Calculations" compares the 10 and 7 regions of interest (ROI) approaches and presents the similarities and differences as well as considerations for improvements and standardization for software sustainability.

T3.5-P67 "Stack Data Processing Pipeline" describes the overall data pipeline of the Source Term Analysis of Xenon (STAX) project as well as a graphical user interface for basic viewing of stack release data.

T3.5-P68 "Study of Variants for Seismic Data Pre-Processing Which Are Not Leading to Significant Losses of Information that May Be Needed" considers pre-processing solutions, such as the wavelet transform, autoencoder and compressive sampling, that do not lead to significant loss of potentially useful information.

T3.5-P71 "The Application of Multi-Criteria Synthetic Method in Discrimination of Nuclear Explosions from Earthquakes" selects various time- and frequency domain characteristics and the results fused by an artificial neural network and Dempster–Shafer evidence discrimination of earthquake and explosion events.

T3.5-P72 "The Challenge of Quantitative Comparison and Quality Assessment of IDC Waveform Bulletins" proposes a unified method of comparison among different catalogues and the use of event magnitude as another parameter of comparison in the process of evaluating the quality of different catalogues.

T3.5-P73 "The Identification and Determination of Small Peaks and the False Positive Alarm in RN Particulate Spectra Analysis" summarizes some cases of spectra analysis and laboratory reanalysis.

T3.5-P74 "The Iterative Processing Framework: A New Paradigm for Automatic Event Building" proposes an iterative processing framework that incorporates automatic analyst behaviours into the event building pipeline and finds that it performs better than the pipeline currently used at the IDC.

T3.5-P75 "The STAX Project. A New Data Source to Aid in Treaty Monitoring" uses high resolution detector systems at medical isotope production facilities to measure the radioxenon released at the source and to better understand the worldwide radioxenon background.

T3.5-P77 "Toward Reliable Certainty for Seismic Processing Tasks with Deep Learning" addresses the problem of assessing uncertainty associated with machine learning data processing results.

T3.5-P79 "Towards Real-Time Association of Infrasound Events Using Full-Wave Modelling" presents a new approach for solving the association problem, using a full-wave propagation model and a Markov chain Monte Carlo algorithm.

T3.5-P80 "Using Spectral Ratios to Discriminate Between Low-Magnitude Earthquakes, Explosions and Mining Events in Canada" shows that amplitude ratios between different parts of the signal can be used to distinguish between explosions and earthquakes.

T3.5-P82 "When Can the Combination of Seismic and Infrasound Data Improve Event Location?" explores the benefit of combining seismic and infrasound data to obtain improved event locations.

Theme 4. Performance 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. The handling of OSI data is also subject to specific requirements outlined in the Treaty and the OSI Operational Manual. In addition, the performance of the IMS and IDC critically depends on enabling technologies such as information technology and power systems. Beyond the IMS, IDC and OSI, the full Treaty verification system also includes NDCs and the possible use of non-IMS data to supplement IMS data. NDCs provide advice to their National Authorities, which make decisions in view of a broader policy context. NDCs may have IMS data and Treaty monitoring functions integrated into national operations and procedures to enhance their performance. NDCs provide feedback to the IDC on its products and services, including the NDC analysis tools, and conduct preparedness exercises jointly with other NDCs. Optimization of the performance of the CTBT verification system involves other factors such as improvements to efficiency and cost effectiveness, reliability, and security. Contributions on improving performance related to the verification system are invited.

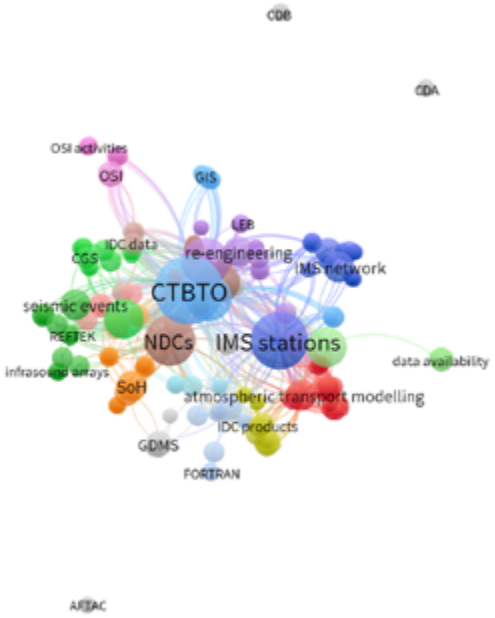


Figure 28. Theme 4. Network visualization by keywords based on the Book of Abstracts (53 abstracts, 280 keywords, 25 clusters). CTBTO Library developed this figure using Mendeley and VOSviewer Software[4].

T4.1 Network Optimization

Highlights

Presentation *Adaptable Turnkey Solution for Infrasound Station* (**T4.1-01**) introduced a new 'a la carte' modular station design approach that allows for station design, including equipment vaults, wind noise reduction systems, power systems and communications, to be tailored to the actual environmental and other conditions of the station.

[4]The size of the bubble corresponds to the number of abstracts that mention the specific keyword in the Book of Abstracts of SnT2019.
The clusters are represented by colours. They are related to which keyword belongs in co-ocurrency. The bubbles in grey represent isolated keywords. Lines between bubbles represent connections between keywords. The distance between two bubbles indicates the relatedness of both in terms of frequency. The closer two keywords are located to each other, the stronger their relatedness.

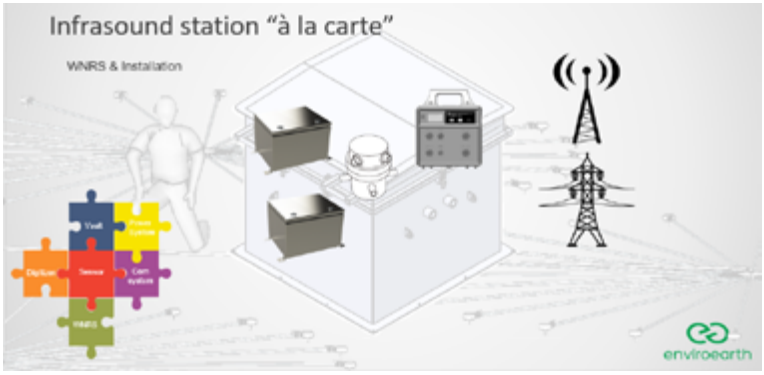


Figure 29. Adaptable turnkey solution for infrasound stations. From R.J.Y. Colbalchini et al. (T4.1-01).

Presentation *Latest Development of the Standard Station Interface Calibration Module* (**T4.1-02**) highlighted the fact that due to the diversity of equipment used in the IMS network, calibration software differs from station to station, causing difficulties for training and the preparation of instructions. The newly introduced standard station interface calibration module helps to address this issue. The goal is to have one user friendly software that can be used with different digitizer and sensor combinations. The calibration results are presented in the approved IMS2.0 format, which standardizes the station operator reports.

Presentation *More Mission Less Money - How to Effectively Optimize Your Network Through Total Life Cycle Management* (**T4.1-03**) described the challenge of sustaining operational success as the focus shifts from network growth to sustainment, where the budget can no longer buy the same performance improvements. A misplaced emphasis on data availability may obscure more actionable metrics such as those provided by network diagnostics, maintenance actions and inventory health. Predictive maintenance approaches with fast issue identification help support more effective resource allocation. The greatest challenge may be the cultural change associated with the introduction of a data-driven approach to decision making.

Poster *Implementation of a QA/QC Programme for Noble Gas Monitoring in the IMS Network* (**T4.1-P13**) demonstrated how the IMS is successfully implementing quality assurance/quality control (QA/QC) calibration standards across the IMS noble gas network by introducing known calibration gases in the instruments and comparing results against laboratory produced measurements.

Poster *Major Upgrade at IS41 Villa Florida, Paraguay* (**T4.1-P19**) described implementation of a new digitizer that enables remote access. Together with systematic improvements to lightning and power protection, this brings improved station reliability.

Poster *New High Quality VBB Borehole Sensor Upgrades and Additional Atmospheric Sensors at Global Seismographic Network (GSN) Stations* (**T4.1-P20**) reviewed quality evaluations performed by Incorporated Research Institutions for Seismology against their extensive global seismic network holdings. The goal of the studies is to better inform decisions on future sensors and the installation of augmenting infrasonic systems.

Poster *Parallel Processing in the GDMS Analysis Pipeline* (**T4.1-P23**) explored modular design approaches to improve data processing and operations monitoring applications. Data on the usage of a standby backup generator was used as an example.

Poster *Next Generation Power Systems of CTBTO International Monitoring System (IMS)* (**T4.1-P33**) presented a standardized modular approach to designing and implementing power systems for IMS stations. The design suggestions are adaptable to local conditions and based on the latest power equipment achievements.

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

***T4.1-01** "Adaptable Turnkey Solution for Infrasound Station" demonstrates how to design and install an infrasound station in an easier and more efficient way, using modules analogy and simple concept blocks supported by real technical solutions.

***T4.1-02** "Latest Development of the Standard Station Interface Calibration Module" presents a tool that extends the standard station interface for intuitive execution of instrumental calibrations and review of calibration results.

***T4.1-03** "More Mission Less Money - How to Effectively Optimize Your Network Through Total Life Cycle Management" demonstrates how the systems engineers of the Air Force Technical Applications Center (AFTAC) in the United States of America successfully implemented a comprehensive approach to total life cycle management with positive results, including increases in network data availability, quality and timeliness, while achieving unprecedented levels of cost savings across the organization.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T4.1-P2 "Bulgarian NDC and Network – New Achievements and Challenges" presents progress made by the Bulgarian National Data Centre in integrating the new SeisComP3 software in seismic data processing with the modules 'scanloc' (detection, clustering and association) and 'sceval' (real time event evaluation) to improve event localization and magnitude determination.

T4.1-P9 "Geodynamic Network of Seismic and Volcanic Monitoring OVSICORI-UNA a Possibility of Data Integration with the Costa Rica National Data Centre (NDC-CR)" presents developments over the past 10 years in the geodynamic network of seismic and volcanic monitoring by Observatorio Vulcanológico y Sismológico de Costa Rica (OVSICORI) that provide an opportunity to integrate data with the National Data Centres of the Latin America and the Caribbean region.

***T4.1-P13** "Implementation of a QA/QC Programme for Noble Gas Monitoring in the IMS Network" presents results of the quality assurance programme and challenges with regard to a network wide quality assurance/quality control (QA/QC) programme involving short lived isotopes and remote station locations.

T4.1-P14 "Implementing Process Oriented Knowledge Management: Lessons Learned from an Application in the OPCW" presents a pilot project initiated by the Chemical Demilitarisation Branch of the Organisation for the Prohibition of Chemical Weapons (OPCW) to identify improvements for its activities based on the evaluation of its knowledge products using process oriented knowledge management methodology.

T4.1-P15 "IMS Station Management in Argentina" shares experience of the Nuclear Regulatory Authority of Argentina in IMS station management, considering administrative and technical factors as well as existing limitations related to maintenance planning, response to urgent repair needs, capabilities and training of local operators, importation of equipment, bidding processes, quality assurance and good practices.

T4.1-P16 "Infrasound Detection Capability Improvement on Noise Reduction System" presents tests performed by two agents/operators from the Nuclear Regulatory Authority of Argentina on the noise reduction system of one array of IMS infrasound station IS2 (Argentina) as part of corrective maintenance measures.

T4.1-P17 "Key Factors that Improved Data Availability at IMS RN Stations" describes key factors that led to improved data availability at IMS radionuclide stations by moving away from corrective maintenance towards preventative maintenance.

T4.1-P18 "Maintenance Visit to Radionuclide Station FJP26 and Auxiliary Seismic Station AS031/MSVF" presents examples of on-site maintenance, troubleshooting and repairs at IMS stations.

***T4.1-P19** "Major Upgrade at IS41 Villa Florida, Paraguay" highlights a major upgrade of IMS infrasound station IS41 (Paraguay) in order to mitigate several technical issues owing to equipment aging and infrastructure deterioration, an upgrade that has led to reliable maintenance, remote monitoring and efficient troubleshooting of the station.

***T4.1-P20** "New High Quality VBB Borehole Sensor Upgrades and Additional Atmospheric Sensors at Global Seismographic Network (GSN) Stations" discusses new technologies that can support fundamental earth science research as well as fulfil the mission of nuclear monitoring and verification.

***T4.1-P23** "Parallel Processing in the GDMS Analysis Pipeline" presents a next-generation system being built by General Dynamics Mission Systems (GDMS) to process incoming files in a faster and more reliable manner through the use of multiple processing nodes, 'smart' processing algorithms and multiple built-in redundancies.

T4.1-P24 "Power Quality and Generator Monitoring" presents advancements in the remote monitoring capabilities of General Dynamics Mission Systems, in particular the addition of state of health monitoring for the auxiliary generator and preliminary testing of a power quality meter for waveform capture and quantification of abnormal power events.

T4.1-P27 "Seismic Station Control" describes an experiment to measure the association digitizer–sensor response to ground excitation by installing 10 seismometers inside a gallery of a dam and monitoring flow through the dam for a period of one week.

T4.1-P28 "Site Selection for Seismic Broadband Station Installation (CGS Seismic BB National Network)" describes the methodology adopted by the Centre National de Recherche Appliquée en Génie Parasismique (CGS) in Algeria to select sites where the national broadband seismic network stations should be installed.

T4.1-P31 "The New Botswana Seismological Network (BSN): Developments in Detection of Seismic Events in Southern Africa and Beyond" presents developments in the new seismological network that will increase the density of stations capable of detecting seismic events, including nuclear tests.

***T4.1-P33** "Next Generation Power Systems of CTBTO's International Monitoring System (IMS)" presents next-generation IMS power systems, offering increased resiliency, added redundancy, trusted components, purpose-built yet standardized power systems, and a high degree of standardization that simplifies installation, maintenance and future upgrades.

T4.2 Systems Engineering

Highlights

The importance of fully engineered complex systems such as the IMS network and the IDC software, which is progressing through re-engineering phase, was emphasized, and through this implementation, is delivering results in terms of optimization, sustainability and meeting stakeholders changing needs and expectations.

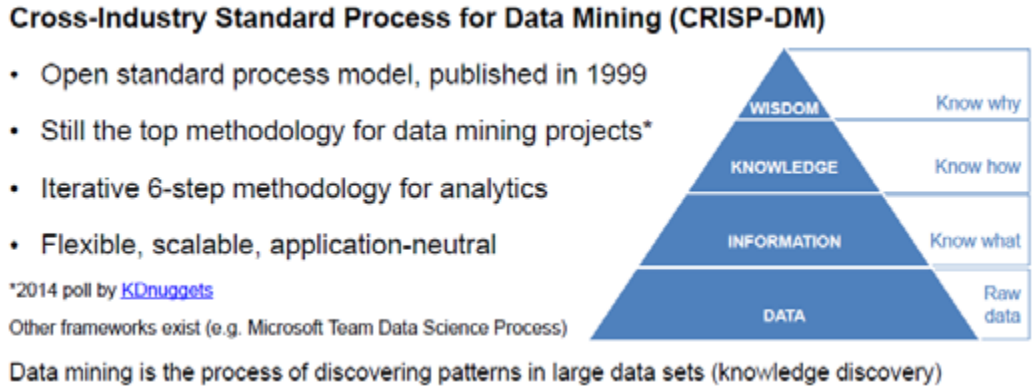


Figure 30. Cross-industry standard process for Data Mining. From P. Benicsak. P and D. Foster. (T4.2-01).

The advances in the analytics of sustainment data is lending further support that sustainment activities of the IMS network should be primarily driven by data-driven decisions.

For the optimization of performance and cost of sustaining the IMS network, and for improving data-driven decisions, further standardization of the station equipment is required.

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

T4.2-01 "A New Approach to Supportability Analysis for the IMS, Based on the Cross-Industry Standard Process for Data Mining (CRISP-DM)" presents the cross-industry standard process for a data mining framework and an example of how it can be applied by the PTS on any level by any Section working in the field of logistics support and/or related analysis.

T4.2-02 "FaultNet: A Deep-Learning Framework for Data-Gap Analysis" presents FaultNet, a deep neural network framework with the potential to reduce outage response time for National Data Centres and improve data availability at the IDC.

T4.2-03 "Geophysical Monitoring System (GMS) Development for IDC Re-Engineering" presents the geophysical monitoring system, a new extensible data processing system for the IDC and States Signatories that provides a platform to improve nuclear test monitoring.

T4.3 Enabling Technologies

Highlights

Poster *Improved Method for the Testing and Verification of the Sierra Instruments 620s Mass Flow Meter* (**T4.3-P6**) presented the results of an IMS radionuclide system airflow sensor performance study involving a PTS standard reference sensor and another commercially available mass flow sensor. Testing methods and the degree of agreement between different sensors under operationally relevant conditions were discussed and quantified. This work is of high relevance to the CTBT and constitutes progress in IMS systems and data centre analysis.

Poster *NDC in the Cloud: Example of Performing Seismic Processing in the Cloud* (**T4.3-P9**) presented a proof of concept study involving commercial data cloud services as a platform for supporting storage and dissemination of a National Data Centre's representative data set via remote cloud based storage and retrieval services. The geophysical data set used in the demonstration was similar to the size and type of data typically

produced by IMS stations. The demonstration highlighted the broad applicability of the proposed approach and the affordability of using a cloud based storage and dissemination scheme for a potentially wide range of users of IMS-like data. This work demonstrated that the advantage of on-demand resource availability has the potential to make cloud computing a viable option for National Data Centres. Using this platform could help to reduce the expense and complexity of purchasing, configuring and managing the hardware and software that is needed for IMS-like data storage and analysis.

Figure 31. Custom designed research cluster in Amazon Web Services used for processing the large United States National Seismic Network dataset. G. A. MacLeod et al. (T4.3-P9). More details here: J. MacCarthy, O. Marcillo, C. Trabant, Seismology in the Cloud: A New Streaming Workflow. Seismological Research Letters, DOI: https://doi.org/10.1785/0220190357

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T4.3-P2 "CTBTO Link to the ISC Database" describes a service that the CTBTO and the International Seismological Centre (ISC) have jointly enabled for the benefit of the monitoring community as a whole and shows how seismological non-CTBTO data, covering a much longer period of time, can be used to assess, calibrate and further advance nuclear test monitoring.

***T4.3-P6** "Improved Method for the Testing and Verification of the Sierra Instruments 620S Mass Flow Meter" presents an improved method for testing and validating the flow meters used in the RASA automatic particulate system in order to accurately determine radionuclide activity concentrations.

***T4.3-P9** "NDC in the Cloud: Example of Performing Seismic Processing in the Cloud" argues that cloud computing resources using scalable infrastructure located regionally may be a way to allow even the most resource-poor National Data Centres to fully participate in the CTBT and advise their National Authorities of pertinent events.

T4.3-P10 "Quantifying the State of Health of a Detection System Remotely with LabPulse" discusses the concept of LabPulse, a live state of health monitoring system for radiological instrumentation that ensures system performance, increases uptime, improves timing of instrument maintenance, watches for faults, reduces time to solve problems and improves overall system reliability.

T4.3-P11 "Temporary Installation of Seismo Wave MB3d with Raspberry Pi at Nanyang Technological University" looks into optimizing array design to increase capability using MB3d microbarometers and off the shelf components for regional volcano infrasound studies combining data from the arrays of the Earth Observatory of Singapore, the IMS and other regional sources.

T4.4 Performance of the Full Verification System

Highlights

The objective of the *3rd ATM-Challenge 2019* (**T4.4-01**) exercise was to stimulate the broad participation of experts, in particular NDCs. The use of forward modelling based on real multiple sources, together with the diverse approaches of the participants, should contribute to enriching ensemble modelling results and better quantifying uncertainties in atmospheric transport modelling simulations for a better understanding of the xenon background at IMS stations, in particular those impacted by industrial emissions, and therefore contribute to optimizing the monitoring capability of the IMS.

Presentation *International Monitoring System's Detection and Screening Capability in Australia* (**T4.4-02**) discussed the current effort to enable the production of earthquake bulletins in Australia that are less dependent upon analyst review of data. The repeated observation was that current automated detections underreported the events significantly. In some parts of the monitored region, analysts significantly increased the number of reported events. The goal of these efforts is to produce a more reliable automated bulletin.
Presentation *Near Real-Time Monitoring of the IMS Event Detection Capability* (**T4.4-03**) discussed possible improvements to the current system for monitoring the detection capabilities of the primary seismic network of the IMS, which was developed years ago. The presentation demonstrated that the performance of the seismic detection threshold monitoring software can be improved significantly thanks to recent advances in computer technology, in particular in terms of time and spatial resolution. The presentation proposed attractive animated methods for displaying results that clearly show the dynamic nature of the detection thresholds. The proposed development would contribute to improving the continuous assessment of IMS performance.

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

***T4.4-01** "3rd ATM Challenge 2019" focuses on the design and development of the third Atmospheric Transport Modelling Challenge, which will address radioxenon background estimation at selected IMS stations.

***T4.4-02** "International Monitoring System's Detection and Screening Capability in Australia" provides insight into the detection and screening capability of the IMS in sparsely covered areas, promotes civil application of data used for test ban verification, and provides an opportunity for improvement of nuclear test monitoring by comparing the Australian bulletin with the Reviewed Event Bulletin.

***T4.4-03** "Near Real-Time Monitoring of the IMS Event Detection Capability" demonstrates ways in which a system for continuous threshold monitoring can be extended to display and investigate the spatial and temporal variability in IMS event detection capability and thereby improve confidence in the performance of the CTBT monitoring system.

Overview of Poster Presentations

T4.4-P2 "An Assessment of XSEL Bulletin as Produced Through the Cross Correlation Technique" assesses the cross-correlation bulletin using events of two days in October 2018 in terms of finding events not present in the Reviewed Event Bulletin and quality and finds that the cross-correlation technique needs additional criteria to reduce the number of false and new seed events and create proper arrival times to produce a bulletin that can be comparable to the Reviewed Event Bulletin.

T4.4-P3 "Build Up Exercises to Validate OSI Capability Development" provides an overview of the objectives and scope of the OSI build-up exercises as well as information on preparations for this organization-wide endeavour and on the inspection activities and techniques to be tested.

T4.4-P5 "Effective Management of OSI Equipment and Software" presents a new browser based asset (software and equipment) management system used by the OSI Division that addresses cross-platform integration and Treaty specific considerations.

T4.4-P6 "High-Density Configuration Experiment of Noble Gas Measurement Systems in Japan" demonstrates how the studies performed on the collected data during these campaigns serve the purpose of calibration and performance enhancement of the IMS verification system.

T4.4-P7 "National Data Centre Preparedness Exercise 2017 - Exploring Real IMS Data for Casual Connections" describes the objective of the exercise, which was to enhance the use of real IMS data and IDC products and services in the everyday work of National Data Centres, and the tasks of the exercise, which covered all IMS technologies.

T4.4-P8 "Quality Assessment of REB Through Comparison with NEIC Bulletin for the Month of September 2018" assesses the quality of the IDC Reviewed Event Bulletin by comparing it with the National Earthquake Information Center (NEIC) bulletin in terms of matched and unmatched events.

T4.4-P9 "Quantifying Uncertainties and Confidence Level in ATM Simulations" studies the impact of different meteorological input coming from an ensemble prediction system to atmospheric transport modelling in order to better estimate the source location and to quantify the level of confidence.

T4.4-P10 "Quantifying Uncertainties in the Atmospheric Modelling (ATM) Simulations Resulting from Different Emission Time Resolution" uses emission data from the Institute for Radioelements in Belgium and the Australian Nuclear Science and Technology Organisation for the full year of 2014 to verify that different emission time resolutions do not significantly affect atmospheric transport modelling performance.

T4.4-P11 "Successes in Improving Data Availability to RN Station with Long Term Issues" demonstrates how long term problems at some radionuclide stations were dealt with by first identifying the root cause of the problems using good diagnostics.

T4.4-P13 "The CTBTO/PTS Operations Centre" presents the performance monitoring parameters, issues and challenges of operating the IMS via the functions and concept of operations of the new Operations Centre (COPC) of the CTBTO.

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 safety. 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. 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 the virtual Data Exploitation Centre (vDEC). IMS data may also be used for civil applications, such as nuclear and radiological emergency preparedness and tsunami early warning. Ensuring that countries and institutions have a robust science–policy interface requires the wide dissemination and appropriate communication of scientific knowledge to both decision makers and the general public. It is therefore important to raise awareness through a broad range of outreach initiatives and science communication.

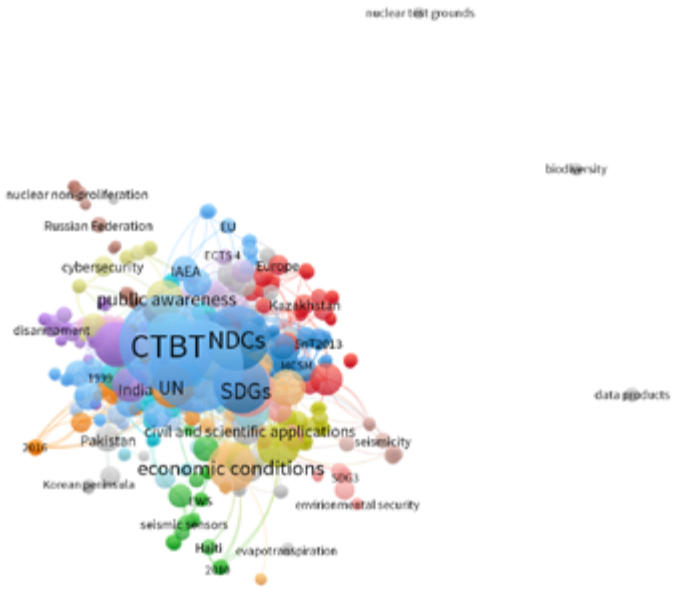


Figure 32. Theme 5. Network visualization by keywords based on the Book of Abstracts (132 abstracts, 511 keywords, 29 clusters). CTBTO Library developed this figure using Mendeley and VOSviewer Software[5].

T5.1 Science in Policy Discussions and Lessons Learned from Other Arms Control Agreements and Arrangements

Highlights

Three oral presentations were delivered under this topic, each of which drew out specific examples of the interrelationship between science and policy in arms control agreements and arrangements.

Presentation *Chemistry and Diplomacy: The Provision of Scientific Advice for Disarmament and Non-Proliferation Treaty Organisations* (**T5.1-01)** discussed how diplomats and other decision makers on policy issues often lack scientific and technical insight necessary to take decisions. The Organisation for the Prohibition of Chemical Weapons deals with this in the case of the Chemical Weapons Convention by providing neutral scientific information on chemical related issues for the benefit of all States, particularly those without scientific advisers. Important success factors for this approach are availability to stakeholders, good science communication skills and tools, and collaboration with other organizations and events such as the SnT conference.

Figure 33. Technology and productivity over time. From J. Forman. (T5.1-01). Figure source: Chemistry and Diplomacy: The Provision of Scientific Advice for Disarmament and Non-Proliferation Treaty Organisations. Gartner, Inc. General hype cycle for technology. CC BY-SA 3.0.

Presentation *Comparative Assessment of CTBT with International Arms Control and Disarmament Treaties: Strengths and Limitations of Science in Enforcement and Addressing Security Driven Actions* (**T5.1-01)** discussed South Asian views on the success or otherwise of the CTBT, which are sometimes based on comparison with other treaties and agreements. There is a perception among some that treaties such as the Partial Test-Ban Treaty, the Chemical Weapons Convention and others found more consensus. Overall, a more integrated and comprehensive approach to arms control is needed, for which political will is currently lacking.

Presentation *North Korea and the CTBT* (**T5.1-03)** discussed the case of the Democratic People's Republic of Korea in the context of CTBT entry into force. While conventional wisdom held that the Democratic People's Republic of Korea could be the most difficult case for CTBT ratification, ongoing developments suggest potential for movement. Lessons can be learned from the application of other arms control instruments. In particular, clarity on terminology, such as the meaning of "denuclearization of the Korean Peninsula" will be important.

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

***T5.1-01** "Chemistry and Diplomacy: The Provision of Scientific Advice for Disarmament and Non-Proliferation Treaty Organisations" discusses how the provision of scientific advice to policymakers, who have no formal scientific training, and the requirement to consider science in decision making can strengthen Treaty implementation.

[5]The size of the bubble corresponds to the number of abstracts that mention the specific keyword in the Book of Abstracts of SnT2019. The clusters are represented by colours. They are related to which keyword belongs in co-ocurrency. The bubbles in grey represent isolated keywords. Lines between bubbles represent connections between keywords. The distance between two bubbles indicates the relatedness of both in terms of frequency. The closer two keywords are located to each other, the stronger their relatedness.

***T5.1-02** "Comparative Assessment of CTBT with International Arms Control and Disarmament Treaties: Strengths and Limitations of Science in Enforcement and Addressing Security Driven Actions" analyses the role of science-driven factors, along with geopolitical, psychological and mutually shared values that rendered certain non-proliferation treaties effective and attempts to understand the configuration of multiple factors that consolidate such treaties.

***T5.1-03** "North Korea and the CTBT" suggests the possibility of adherence by the Democratic People's Republic of Korea to the CTBT, drawing on lessons learned from other arms control instruments.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T5.1-P4 "Leveraging the CTBT's Verification Provisions for Promoting Entry-into-Force" discusses why the verification provisions of the CTBT, although rigorous, are insufficiently leveraged to promote entry into force.

T5.1-P5 "On-Site Inspection: A Multidimensional Example of Science Diplomacy" applies and operationalizes three dimensions of science diplomacy, i.e. diplomacy for science, science in diplomacy and science for diplomacy, to OSI, a key specific element of the verification regime of the CTBT, in order to provide a more tangible and practical overview of the interactions and interface between science and diplomacy.

T5.1-P7 "Testing Customs: The CTBT and Customary International Law" underscores the importance of the scientific community, women and youth to the CTBT in its role within the international legal landscape, as a treaty and as a building block of custom.

T5.1-P8 "The Development of Arms Control Agreements and Arrangements" aims at encouraging further discussion on the topic of arms control agreements and arrangements by covering data from all fields of study.

T5.2 Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals

Highlights

In order to strengthen the support for the CTBT around the world, it is important to emphasize its potential civilian applications. These include tsunami, volcano, earthquake and landslide warnings as well as the monitoring of life under water. Other potential uses include monitoring of air pollution and research of biodiversity changes.

The CTBTO should ensure the use of its data for disaster risk reduction given that States Signatories require assistance in developing effective warning systems for natural disasters, as noted in *Amplifying the Impact of CTBTO Data for Emergency Response and Climate Change Monitoring* (**T5.2-06**) and *The Invisible Link Between the Sendai Framework for Disaster Risk Reduction and CTBT* (**T5.2-011**).

Such use of CTBTO data would also contribute to the sustainability and expertise of National Data Centres, as presented in *Recent Seismic Activities in Ghana: The Role of the National Data Center (NDC)* (**T5.2-P28**).

Capacity building programmes through geo-hazards training, monitoring and warning activities should become key elements of the long term science and technology activities that use IMS data.

Detection, processing and analysis of hydroacoustic signals by the IMS is significantly contributing to the monitoring of ocean phenomena such as tsunami waves and storm surges, coastal and submarine slides, underwater explosions, but also life below water (United Nations Sustainable Development Goal 14), as discussed in *CTBTO IMS Contribution to SDG14: Life Below Water* (**T5.2-02**).

Figure 34. H8S detect events from Azimuth 150 – 200 and constantly on 25°. From I.V Kursenko and J. Adriamampandry. (T5.2-02).

Over the long term, such sustained and robust networks would always allow better understanding of the evolution of such phenomena and animals.

Tsunami threats became globally understood following the 2004 Indian Ocean disaster, as highlighted in *Hazard Mitigation Analysis of the Anak Krakatau Eruption and Its Tsunami (22 December 2018)* (**T5.2-04**).

Tsunamis are a significant natural hazard and risk induced by earthquakes, landslides and volcanic eruptions. Tsunamis threaten and could impact a large number of countries bordering seas and oceans. The Gunung Anak Krakatau eruption demonstrates how the potential impact of tsunami waves induced by landslide and/or volcano collapse could be disastrous.

Presentation *Infrasound Monitoring of Active Volcanoes at Local and Regional Scale* (**T5.2-05)** demonstrated the capabilities of the IMS infrasound network to monitor volcanic eruption activities, in particular for the Etna and Iceland volcanoes. The potential capabilities of the current IMS network show than the average distance from volcanoes to the closest IMS infrasound station is less than 1000 km, with a detection delay of about 50-60 minutes.

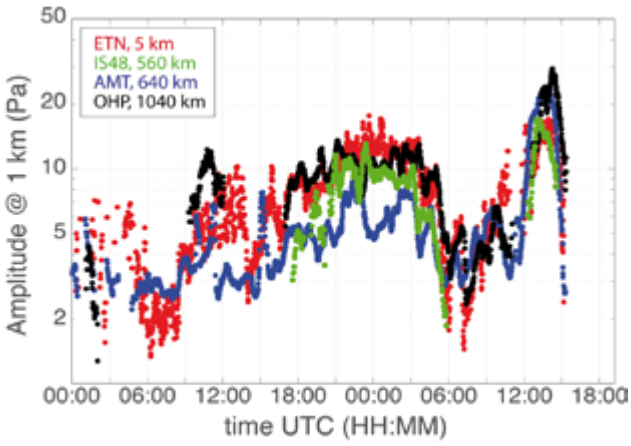


Figure 35. Etna lava fountain 18 May 2016. Once corrected for attenuation the pressure time history can be reconstructed even from stations located hundreds of kilometres away from the source. From E. Marchetti et al. (T5.2-05). More details in: E. Marchetti et al, Long range infrasound monitoring of Etna volcano. Scientific Reports 9, 18015 (2019). DOI: https://doi.org/10.1038/s41598-019-54468-5.

Presentation *"Feasibility Assessment for Geothermal Potential"* (**T5.2-03**) highlighted research on seismicity and active seismic faults that would provide knowledge for a geothermal power supply to build a sustainable world. The seismic hazard maps built with such data would contribute to defining the regions where anti-seismic industrial and power plants should be implemented.

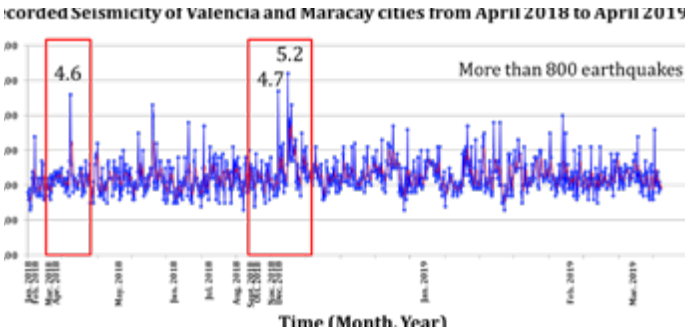


Figure 36. Recorded seismicity of Valencia and Maracay from April 2018 to April 2019. From K.C. Ramirez Loaiza et al. (T5.2-03).

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

T5.2-01 "CTBTO for UN 2030: Empowering Diplomacy Through Science in South Asia" challenges the lack of interdisciplinary coordination of expertise, or 'siloisation', in the policy narrative around the CTBT in South Asia.

***T5.2-02** "CTBTO IMS Contribution to SDG14: Life Below Water" reveals the diverse contributions of the IMS to United Nations Sustainable Development Goal 14, in particular to tracking the paths of cyclones and detecting whales and other species.

***T5.2-03** "Feasibility Assessment for Geothermal Potential in Las Trincheras - Mariara, Venezuela" presents a project that incorporates CTBTO and temporal local seismic stations to densify the station grid and update geological and geophysical information in order to improve scientific understanding of the given geothermal process.

***T5.2-04** "Hazard Mitigation Analysis of the Anak Krakatau Eruption and Its Tsunami (22 December 2018)" shares an analysis of hazard mitigation and experiences from the tsunami generated by the Anak Krakatau eruption, which caused many casualties in the Banten and Lampung provinces of Indonesia.

***T5.2-05** "Infrasound Monitoring of Active Volcanoes at Local and Regional Scale" shows how frequency dependent semi-empirical relationships derived from parabolic equation simulations coupled with realistic atmospheric profiles allow correcting for attenuation and reconstructing the pressure time history with great accuracy.

***T5.2-06** "Amplifying the Impact of CTBTO Data for Emergency Response and Climate Change Monitoring" presents an integration of technical IMS data with social media resources in order to increase the efficacy of the global response to natural disasters or human-made environmental catastrophes, ultimately garnering science and innovation for the social good.

T5.2-08 "Renewable Energy and Sustainable Development in the Light of Environmental Security" highlights the role played by alternative energies in achieving sustainable development and discusses the most important environmental and security challenges of nuclear power plants and the importance of their peaceful use as a source of sustainable development and environmental security.

T5.2-09 "The Catastrophic Failure of the Iron-Ore Tailings Dam: The Worst Environmental Disaster in Brazil" presents innovative synergy between the infrasonic and seismic technologies for monitoring detonations in quarries.

T5.2-010 "The CTBTO and Goal 11: Using the IDC to Make Cities Safer and More Inclusive Through Disaster Preparedness Laws (CTBTxSDGs Innovation Challenge)" demonstrates the intersection between the CTBTO technologies and data centres and the United Nations Sustainable Development Goals aimed at promoting sustainable, resilient human settlements.

***T5.2-011** "The Invisible Link Between the Sendai Framework for Disaster Risk Reduction and CTBT" focuses on how the European Natural Hazard Scientific Partnership Project ARISTOTLE operates and how CTBTO data can assist multi-hazard early warning systems and therefore support the Sendai Framework.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T5.2-P1 "Activities of the Ghana Nuclear Data Centre (NDC)" presents the activities and objectives of the National Data Centre of Ghana.

T5.2-P4 "Contributions to Issues of Global Concern such as Disaster Risk Mitigation" demonstrates how properly interpreted IDC data may predict or prevent some disasters based on two concrete cases.

T5.2-P6 "CTBT Technology for Securing SDG 6: Ensure Availability and Sustainable Management of Water and Sanitation for All" argues that the non-proliferation of nuclear weapons must concern us all and that we should all be aware of the importance of the ratification of the CTBT and the verification

and monitoring of nuclear testing, as nuclear testing could contaminate the water supply of many communities.

T5.2-P17 "Integration of the IMS Waveform Technologies for Tsunami Early Warning: A Perspective from Venezuela and the Caribbean" describes efforts to include the Caribbean tsunami warning centres and National Data Centres in the disaster warning initiatives of the CTBTO and the use of infrasonic stations along with seismic and hydroacoustic stations.

T5.2-P22 "Modern Seismic Network Development in Iraq" presents the expansion of seismic networks, monitoring and research in Iraq in partnership with the U.S. Department of Energy's Seismic Cooperation Program through the Lawrence Livermore National Laboratory.

T5.2-P24 "Operational Readiness of CTBT Hydroacoustic Stations in Achieving Sustainable Development Goal 14" investigates the operational readiness of hydroacoustic stations by examining literature over the past 10 years and concludes that 90% of the IMS hydroacoustic stations are ready to contribute data that could be used to carefully manage life below water.

***T5.2-P28** "Recent Seismic Activities in Ghana: The Role of the National Data Centre (NDC)" highlights the civil and scientific benefits of the CTBTO and the achievements of the Ghana National Data Centre in seismic disaster risk mitigation through public awareness, capacity building, education and collaboration with other State institutions.

T5.2-P29 "Remote Sensing Earthquake Ground Motions Using Seismo-Acoustic Coupled Signals" shows how infrasonic signals recorded by IMS infrasound arrays can be used to resolve earthquake ground motions, even in regions without seismometers.

T5.2-P38 "Swedish Biodiversity in Time and Space" describes how weekly air filters from six locations throughout Sweden have been utilized for about 50 years to examine biodiversity in Sweden over time by sequencing the DNA captured in these filters and how they are now being used to study the response of the ecosystem to a changing environment and to track important pathogens to humans, agriculture and livestock.

T5.2-P45 "The WHO and the CTBTO: Joint Initiatives to Address Air Pollution in the Cities" argues that cooperation between the CTBTO and the World Health Organisation (WHO) is crucial to address air pollution and to achieve United Nations Sustainable Development Goal 11 of sustainable cities and communities.

T5.2-P47 "Tsunami Risk Assessment in South-Eastern Mediterranean" performs a qualitative tsunami risk assessment by combining hazard and vulnerability levels for residential buildings and argues that the implementation of an early warning system for the coast of the eastern Mediterranean is becoming an essential and urgent need.

T5.2-P48 "Urban Seismic Risk Evaluation for Georgia" investigates intensity based vulnerability for the City-Museum Reserve of Mtskheta in Georgia by reviewing the building inventory and estimating seismic risk in terms of damage and economic losses for the city.

T5.3 Capacity Building, Education and Public Awareness

Highlights

Presentation *CTBT and Role of the CYG in the Korean Peace and Denuclearization Process* (**T5.3-01**) was interesting because the presenter is not from the Korean Peninsula but wanted to contribute to the peace process. The session served as a connection between the efforts of the presenter and those of regional experts to support this activity.

Presentation *Integration Women Technicians in CTBTO* (**T5.3-03**) discussed activities to empower women for lifelong learning towards a career in science in support of the CTBT. The authors conducted a survey and then attempted to identify an effective structure for women's involvement in science on the basis of the survey results.

Presentation *Nurturing the Science and Diplomacy Generation to Advance the CTBT* (**T5.3-06**) highlighted the need to provide opportunities for students to learn more about science diplomacy, the CTBTO and its verification regime and to provide a platform for cross-disciplinary multicultural and inter-institutional collaboration.

Presentation *Raise the Nuclear Awareness for the Public Across Culture* (**T5.3-08**) noted that the general public is fearful of nuclear weapons and skeptical in relation to the peaceful use of nuclear technologies in civil applications and that the CTBTO should play a role in addressing this matter.

Overview of Oral Presentations

[* indicates that the item is mentioned under Highlights above]

T5.3-01 "CTBT and Role of the CYG in the Korean Peace and Denuclearisation Process" discusses the important role the CTBTO can play in the inter-Korean diplomatic peace process.

***T5.3-03** "Integration Women Technicians in CTBTO" presents research on how to draw women to technical posts at the CTBTO by ensuring equality in education and career building.

T5.3-05 "NRNU MEPhI as an Educational Site for Relevant CTBTO Problems Solving" presents the contribution of the National Research Nuclear University (NRNU) Moscow Engineering Physics Institute (MEPhI) to the CTBTO Youth Group and discusses the potential for further cooperation.

***T5.3-06** "Nurturing the Science Diplomacy Generation (SDG) to Advance the CTBT" shows how the CTBTxSDG project provides unique opportunities for students to learn more about the Treaty through interactive activities, role playing, creative tasks and online conferences, thereby nurturing a generation of enthusiastic science diplomats to effectively promote the Treaty.

***T5.3-08** "Raise the Nuclear Awareness for the Public Across Culture" makes the case that the CTBTO should work with the local institutions of States Signatories to eliminate cultural barriers and actively engage in nuclear education.

T5.3-09 "Raising Public Awareness Among Students About CTBT in Nuclear Age" examines how the CTBT serves as a useful tool with which to learn and/or discuss a variety of topics, including the threat of nuclear proliferation, the use of diplomacy, the art of negotiation, the operation of international organizations and the impact of the Science and Technology conference among the youth.

T5.3-010 "Role of Civil Society Organizations for Education and Public Awareness" argues that it is imperative that civil society organizations influence the authorities to introduce the CTBTO and its mission in the education system in order to achieve a general culture of peace and a life without nuclear arms and nuclear tests.

T5.3-011 "The Intrinsic Value of CTBTO Workshops, Training Programs, and Expert Meetings" highlights how such CTBTO activities improve the monitoring and verification of the CTBT, enhance knowledge exchange, strengthen engagement of the scientific community and identify scientific developments.

Overview of Poster Presentations

[* indicates that the item is mentioned under Highlights above]

T5.3-P1 "20 Years of Participations in CTBTO Activities" shares personal experience as a participant in numerous CTBT capacity building activities, training courses and OSI activities over a 20 year period.

T5.3-P2 "Awareness Activities Related to CTBT Undertaken by HANEA" presents the Niger High Authority for Atomic Energy (HANEA) and its activities to raise awareness of the CTBT amongst government representatives, parliamentarians, scientists and engineers, the media and civil society.

T5.3-P3 "Awareness of the Radionuclide Monitoring Technology for Myanmar's Students" demonstrates how the functioning of IMS radionuclide station RN42 (Myanmar), including air sampling, filter preparation, gamma detector counting and data transmission to the IDC, is explained to undergraduate students as a first step of sustainable learning.

T5.3-P6 "Capacity Building in Central Asia to Monitor the CTBT" presents the joint project between the Norwegian Seismic Array (NORSAR), the Institute of Geophysical Research (IGR) in Kazakhstan and the Institute of Seismology of the Academy of Science of the Republic of Kyrgyzstan and explains how the project helps to integrate the efforts of Central Asian countries in support of the CTBTO.

T5.3-P10 "Cloud Platform as Instrument to Enhance Capabilities of Remote Users (Data Processing and Training)" describes the advantages of the cloud platform for the processing of geophysical data that the NDC Ukraine had deployed in 2016 and offers it for testing and subsequent use in other NDCs and for capacity building and training.

T5.3-P17 "CTBT-SDGs-Innovation-Challenge: Building Resilient Communities Through CTBT Science Information Sharing" presents the efforts of the Young Professionals Network and the National Data Centre of Namibia to build resilience of the poor and vulnerable and to measure the effectiveness of employing novel communication techniques to convey scientific information to affected rural communities using IMS data and IDC products.

T5.3-P18 "CTBTO Educational Programme and Sustainable Development Goal 5 in Nigeria" examines the CTBTO educational programme under the prism of United Nations Sustainable Development Goal 5 of gender equality and concludes that although what is being learned and how it is being learned are adequate, factors like time constraints, infrastructural resources and conflicting priorities limit the participation of women in the CTBTO educational programme.

T5.3-P22 "Engaging Young Generation: The Case of Ural Federal University in Russia" demonstrates how youth in the Russian Federation consider their role in promoting the CTBT and the non-proliferation regime.

T5.3-P26 "Estimation of Ionizing Radiation Risk and Their Effects as a Method of Approach to Data Products" demonstrates the pillars of ionizing radiation risk estimation and its effects as an approach to conventional products.

T5.3-P28 "Extended-NDC-in-a-Box Experience at the Israel National Data Centre" summarizes the experience of the National Data Centre in Israel in implementing and adapting the extended NDC in a box software package.

T5.3-P29 "Feminist Perspective on Disarmament" argues that the dichotomy of seeing disarmament issues from either a realist or liberalist international relations perspective is one of the primary reasons why progress towards the ratification of the CTBT has been sluggish and notes that the feminist perspective offers crucial insight about this.

T5.3-P31 "How the CTBTO Activities Increases and Develops the NDCs Technical Staffs Knowledge, Experiences and Skills, JO-NDC as an Example" highlights the usefulness of National Data Centre technical staff participating in CTBTO activities such as training, workshops and conferences.

T5.3-P33 "Implementation of Research and Development Obligations of the Republic of Kazakhstan on CTBT" presents the results of longstanding IMS work under the 2007 agreement between the CTBTO and Kazakhstan on the implementation of activities, including post-certification activities at IMS facilities in Kazakhstan.

T5.3-P38 "International Outreach and Training on the Regional Seismic Travel Time (RSTT) Method" discusses training given to National Data Centres and researchers across seven continents on the regional seismic travel time method, which has introduced a 3-D regional model for improved travel time prediction and determination of seismic event locations, standardized event location practice and ensured consistent event location results.

T5.3-P40 "KAIST NEREC for Developing Human Capital for Global Nuclear Non-Proliferation" highlights the importance of human capacity building for nuclear non-proliferation and emphasizes multidisciplinary, multicultural, participatory learning through collaboration with the global community of nuclear non-proliferation experts.

T5.3-P42 "Monitoring Compliance with the CTBT – Contributions by the German NDC" presents a book on the contributions of the German National Data Centre, including studies on the institutional, technical and scientific aspects of the CTBT.

T5.3-P44 "National Data Centre's Training Cycle Approach" presents the approach adopted by the Capacity Building and Training Section of the IDC Division of the CTBTO to optimize its training programme.

T5.3-P46 "NNRA Information Dissemination Strategies" presents the goal of the Nigerian Nuclear Regulatory Authority (NNRA) to reduce human error by operating various information dissemination channels to raise awareness, educate and train the decision makers and the public on nuclear issues.

T5.3-P47 "Non-Proliferation Culture as a Subject for Master Degree Curriculum in Technical University of Moldova" focuses on the importance of education and presents the efficiency of the postgraduate course on Nuclear Security and Non-Proliferation in the Republic of Moldova.

T5.3-P55 "Raising Awareness of Nuclear Non-Proliferation Through the Capacity Building System (CBS) in Iraq NDC" demonstrates how using the capacity building system to locate earthquakes promotes the wider civil and scientific applications of techniques and data used for test ban verification.

T5.3-P57 "Regional Training Centre - South African Perspective" presents the South African regional training centre for the Assistance and Protection course and the Analytical Chemistry course of the Organisation for the Prohibition of Chemical Weapons.

T5.3-P62 "Technical Support Provided to States Parties and Its Impact on Process of Promoting Ratification of Treaty" makes the case that the States Signatories should use the support provided by the CTBTO to carry out universal requirements of the Treaty by promoting those requirements and organizing programmes and events.

T5.3-P63 "The Application of International Monitoring System Data (IMS) and International Data Centre (IDC) Products at the Jordanian National Data Centre" presents how the Jordanian National Data Centre and the Jordan Seismological Observatory apply IMS data and IDC products and how the NDC has greatly benefitted in terms of building up its capability as well as enabling its participation at the international level.

T5.3-P64 "The CTBT's Relevance to the SDGs: A Virtual Education Platform for Capacity-Building" presents a project that aims to educate American high school and university science, technology, engineering and mathematics (STEM) students about the CTBT and its contributions to the 2030 Agenda for Sustainable Development, with a specific focus on the United Nations Sustainable Development Goals of sustainable cities and communities, climate action and life below water.

T5.3-P66 "The Effect of Art Students' Awareness of Nuclear Weapons on Their Artistry" discusses how artists can use their work to express their reactions to the nuclear arsenal and sensitize the public.

T5.3-P68 "The Importance of Promoting the CTBT Locally and the Benefits of Doing So" presents effective tools that can be used immediately to promote the CTBT and the effects of carrying out promotional activities to secure future human capital to continue work on the CTBT.

T5.3-P71 "The Role Media Can Play in Raising Awareness of the CTBTO Goals" argues that the reach of the worldwide media to communicate scientific knowledge to decision makers and the public should be exploited to help the CTBTO in achieving its goals and accomplishing its essential mission and suggests ways to accomplish this.

T5.3-P76 "Travelling School" presents an educational and inclusive travelling life course for people of different ages, affiliations, nationalities and levels of education, primarily in Annex 2 countries that have not yet ratified the Treaty.

T5.3-P79 "Understanding of Nuclear-Weapons-Related Issues Among Practitioners in Indonesia" identifies the problems in engagement between the community involved in nuclear issues in Indonesia, those responsible for decision- and policymaking and the general public.

4. Panel Discussions

4. Panel Discussions

The panels are summarized in this chapter in the chronological order in which they appear in the programme. All panels are represented with a short summary followed by the highlights of the discussions. Appendix 2 contains a list of all panellists and moderators with their affiliation.

4.1. CTBT Science and Technology in a Changing World

Izumi Nakamitsu, United Nations Under-Secretary-General and High Representative for Disarmament Affairs, Romain Murenzi, Executive Director of the The World Academy of Sciences and Jennifer Thomson, President of the Organization for Women in Science for the Developing World speaking at the High Level Panel on CTBT: Science And Technology in a Changing World, moderated by Sanam Shantyaei from France24.

This panel reflected on the role of science and technology in meeting modern day challenges, particularly regarding peace and security, and explored the role of the CTBT in this regard. It also considered how to broaden access to science and technology as well as to careers in these domains.

Highlights

The panellists emphasized that the scientific technologies are crucial for verification of nuclear non-proliferation and disarmament. There has always been a close link between scientific expertise and efforts towards building peace and security. The CTBT is an instrument underpinned by a technology-led verification regime, and this global public good should be cherished.

Despite the international security atmosphere being tense, all hope is not lost, according to the panellists. The international nuclear non-proliferation architecture, with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) as its cornerstone, was not at risk of collapsing. The 2020 Review Conference of the Parties to the NPT may be more successful than anticipated.

Global policymaking needs to benefit from increased participation by women and youth in the STEM disciplines. There are various means of achieving this. Specifically, the United Nations is emphasising gender parity in its own organization and in general. Civil society organizations are also highlighting the transformative role of science education for people in developing countries. More knowledge of science in all countries and regions will lead to better decision making.

4.2. Forum on Global Citizenship and Youth Inclusion

Forum on Global Citizenship and Youth Inclusion, co-organized with the Ban Ki-moon Centre for Global Citizens.

The Forum on Global Citizenship and Youth Inclusion, jointly organized with the Ban Ki-moon Centre for Global Citizens, the CTBTO Youth Group and the United Nations Youth and Students Association of Austria, discussed the involvement of youth in the implementation of the United Nations Sustainable Development Goals with a focus on peace and security. The forum opened with remarks by former President of Austria and Co-Chair of the Ban Ki-moon Centre Heinz Fischer and CTBTO Executive Secretary Lassina Zerbo, followed by an interactive panel discussion using audience participation tools.

Heinz Fischer, former President of the Republic of Austria, delivered a keynote speech at the conference.

Highlights

The forum emphasized the importance of a global citizenship mindset for the implementation of the SDGs and discussed the role of youth in related decision making processes. United Nations Security Council Resolution 2250 (2015), which highlights the positive role young people play in maintaining and promoting development, peace and security, was highlighted as important in this regard.

The forum found that young people are increasingly driving the agenda on sustainable development and climate change action, with movements such as Fridays for Future gaining momentum. This shows an emerging understanding of the role of youth as global citizens.

Those in government and other positions of power must be prepared to listen to the concerns and suggestions of youth, not just because they are future leaders but also because they are current stakeholders. The concept of intergenerational equity was found to be key for areas of global concern, from climate change to nuclear non-proliferation.

Regarding the CTBT, the growing role of the CTBTO Youth Group in advocating for the ratification of the Treaty was demonstrated as an example of how youth can act to change minds in countries that have not yet ratified. Young people can reach countries and regions through their own networks where other methods of advocacy have been ineffective.

4.3. Aplicaciones Civiles y Científicas y Programas de Capacitación de la OTPCE: Un Bien Global para la Comunidad Internacional

CTBTO Civil and Scientific Applications and Capacity Building Programmes: A Global Good for the International Community

Ambassador Marcel Fortuna Biato, Ambassador Alicia Buenrostro Massieu, Ignacio Cartagena Núñez, Ambassador Luis Gallegos Chiriboga, Emma Polanco Melo and Minister José Fidel Santana Núñez speaking at the roundtable discussion in Spanish on CTBTO Civil and Scientific Applications and Capacity Building Programmes: A Global Good for the International Community, moderated by Jordi Kuhs from Agencia EFE.

For the first time in the SnT conference series, diplomats and scientists exchanged ideas in Spanish on the contribution of CTBT technologies and data to strengthen national and international capacity for disaster management preparedness and sustainable development. Innovative in its format, the roundtable also offered an opportunity to highlight the link between multilingualism and multilateralism, in particular in the context of highly technical treaties and organizations.

Highlights

Eminent speakers from the diplomatic community, from Ministries of Science and Technology and Foreign Affairs, as well as from academia shared their experiences with the benefits of CTBTO technologies, data and capacity building programmes. In particular, they highlighted these activities as a means to strengthen national and regional disaster management capacity and promote sustainable development.

Both speakers and members of the audience underlined the value of fostering such discussions in Spanish, allowing experts to fully express their positions and contributions. They emphasized the link between multilingualism and multilateralism, in particular within the context of highly technical treaties and international organizations.

4.4. Promotion de l'Entrée en Vigueur du TICE – Perspectives et Initiatives

Boosting CTBT Entry into Force: Perspectives and Initiatives

Ambassador Maria Assunta Accili Sabbatini, Ambassador Faouzia Boumazia Mebarki, Ambassador Roger Albéric Kacou, Jacques Krabal, Rémi Quirion and Ambassador Malik Sarr speaking at the roundtable discussion in French on Boosting CTBT Entry into Force: Perspectives and Initiatives, moderated by Alain Foka from Radio France International.

For the first time in the SnT conference series, a roundtable discussion was conducted in French, as a means to enrich the debate on new perspectives and to encourage CTBT membership and stimulate its entry into force. The importance of the link between science and diplomacy, the role of parliamentarian diplomacy, the relevance and value of regional networks and initiatives, as well as the perspectives of developing countries was addressed.

Highlights

With the key participation of eminent francophone diplomats and high ranking officials of the Organisation international de la Francophonie, including its parliamentarian arm and a high ranking scientific adviser, the debate explored novel and effective avenues to encourage CTBT membership, which will be actively pursued by the CTBTO.

In particular, the panellists highlighted the relevance of the science and diplomacy approach; the value of francophone networks and parliamentarian diplomacy; the necessity to include and develop expertise through capacity building programmes and scientific and civil applications of the verification technologies; and the involvement of youth networks.

Many members of the audience emphasized the value of fostering such debate in French, allowing francophone experts to fully express their positions and contributions. They expressed appreciation for this concrete testimony of the commitment of the CTBTO to multilingualism, a sign of strong and equitable multilateralism.

4.5. Women in Science and Technology

The purpose of this discussion was to examine the obstacles that hamper real gender equality in the field of science and technology and to discuss policies that might help improve the current state of affairs at the national, regional and global levels.

Sabah Al Momin, Sanghamitra Bandyopadhyay, Joanna Bartley, Grace Liu and Alena Yakovleva speaking at the panel discussion on Women in Science and Technology.

Highlights

The panel discussed the social, institutional and cultural biases against women in scientific and technological domains, noting that societies continue to reinforce gender differences and portray women as persons in "need of care and protection" instead of professional, capable individuals and providers for families and communities.

Institutionally, leadership in technology and science fields continues to be mostly male dominated for a variety of reasons. Men occupy the majority of the leadership positions in laboratories and research centres. As they tend to retire later in life, leadership and generational changes are slow to come about. In addition, critical domains such as hedge funds, which are vital to provide necessary funding for research and technological innovation, continue to be dominated by men and may unconsciously operate with gender biases that favour research projects led by men.

Institutions and companies that embrace inclusion and diversity perform better and are more innovative and profitable. Therefore the quest for gender equality and inclusion in scientific and technological fields should not be perceived as a women's problem. Instead, it should be seen as a performance and organizational issue and tackled accordingly.

Talking about gender inclusion is not sufficient. Top leadership has to make a conscious effort to restructure teams and assign leadership positions to women.

A true intergenerational dialogue among women has to take place. The generation of professional women who are coming of age today takes for granted many past achievements in women's equality and inclusion. For this reason, millennial women do not typically consider gender bias a problem. However, without conversations on inequality, structural and institutional obstacles will remain, despite the remarkable progress women have achieved in all sectors.

4.6. CTBTO Youth Group: Agents of Change for Progress of CTBT Entry into Force

Marzhan Nurzhan, Gaopalelwe Santswere, Tatsujiro Suzuki and Hind Touissate speaking at the panel discussion on CTBTO Youth Group - Agents of Change for Progress of CTBT Entry Into Force, moderated by Elena Sokova.

The panel explored the many forms of youth activism in advancing the goals of peace, development and security. It discussed what institutional changes need to be made to strengthen peace education around the world so as to prepare the new generation of peace builders to face global challenges. Finally, it highlighted how young people, through CTBTO youth initiatives, are mobilizing to raise awareness of and generate political support for the CTBTO and its mission.

Highlights

The panel discussed mechanisms by which young people are able to exercise their voice and encourage social and political changes. In addition, panellists examined ways in which educational institutions should improve their educational curricula to better prepare the new generation to confront the many security challenges of today's world.

One of the findings was the fact that young people are willing to mobilize if they feel that an issue is personally relevant. Therefore policymakers and educators have to make an effort to explain why challenges that seem very disconnected from daily life, such as nuclear disarmament and proliferation, are instead collective problems that require individual involvement. The way in which science is communicated to young people is critically important. Creative new tools are needed to engage the young generation in science and technology disciplines. For example, information should be made more accessible by simplifying the language (although not the message) and by encouraging inclusivity and diversity in the classroom.

When is the right time to teach young people about nuclear disarmament? It depends on the communication tools available and the message. Waiting until students pursue an advanced degree is too late. High school students, for example, can be engaged through study projects and fellowships to travel abroad and experience other cultures and viewpoints. Understanding of history is critically important to raising a generation of global minds who are aware of the trauma of the past and willing to work to overcome it. Both scientific and policy students have to be taught history at all educational levels. We have to switch from national educational curricula to global citizenship education where young people are taught not only to think narrowly about the national interests of their respective countries but also about the collective interests and the common goals of humanity.

Finally, it was noted that social media have revolutionized the way in which young people can exercise their voice and demand attention to the issues they care about. Although social media may also be distorted, in many developing countries it serves as a tool for freedom of expression that has to be protected and expanded.

4.7. Communicating Science

James Gillies, Yael Lavie and Karin Orantes speaking at the panel discussion on Communicating Science, moderated by François Murphy.

Science drives the CTBT's continuous monitoring of the planet, as well as its inspection capabilities. However, incomprehension of the language of science by policymakers and the public remains an obstacle that hinders broader support for the Treaty and its entry into force. Journalists and scientists discussed the best ways to communicate science and how understanding of the civil and scientific relevance of the monitoring network can, by association, increase understanding about the need to ratify the Treaty. The panel started with a short documentary that went behind the scenes at the CTBTO, as a waveform data analyst described what it was like to work on 3 September 2017, when the Democratic People's Republic of Korea announced that it had conducted a nuclear test.

Highlights

The introduction to the panel noted that science is at the heart of what the CTBTO does and highlighted the importance of emphasizing other uses of CTBTO data to draw attention to scientific work that is of interest to the general public.

One panellist observed that people like stories, including science stories, and that communication is about telling stories. Furthermore, through telling these stories, a science organization must establish itself as the trusted and authoritative voice in the public conversation on the topic. Even if the more complex details of the science might not be readily understood, audiences do understand the value of science and the value of the scientific method.

A news producer, journalist and university lecturer in media ethics used her experience to discuss ways to reach audiences in parts of the world where the CTBT narrative is difficult to communicate. Reaching young people is key, she noted, but requires adaptation to the way that this generation accesses and consumes news. Instead of television, young audiences rely on social media and forums, which are echo chambers where the messages they are interested in are amplified. These echo chambers need to be penetrated to reach the audiences with the CTBTO's message. It is important to personalize every story and keep it short, to target the attention span of the social media generation. Visualization and personalization are key to communicating science stories.

Another panellist observed that organizations are also using social media to listen, to bring the discussion back to something that people can relate to. Regarding the challenges of communicating the core values of United Nations organizations and their work, she noted the importance of avoiding being caught in a bubble of organizational speak and acronyms. The message must be simple, brief and accessible to audiences who have no background knowledge. Addressing simple questions such as "what does the CTBTO have to do with your life?" is key. Finally, it was recommended that before being published, social media messages should be read from the perspective of people who are not specialists.

4.8. CTBTO and the 2030 United Nations Agenda for Sustainable Development: Strengthening the Link

Ambassador Abel Adelakun Ayoko, Ambassador John Bernhard, Ana María Cetto and winners of the CTBTO Youth Group CTBT Innovation Challenge speaking at the CTBT Innovation Challenge Presentation and Discussion: CTBTO and the 2030 United Nations Agenda for Sustainable Development: Strengthening the Link, moderated by Angela Kane.

The CTBT verification technologies and data collected by the IMS have strong potential to yield compelling civil and scientific benefits. The panel examined potential linkages between the CTBT and the United Nations Sustainable Development Goals and highlighted the innovative proposals made by the CTBTO Youth Group finalists of the CTBT Innovation Challenge: Towards Securing Sustainable Development.

Highlights

The CTBT verification technologies and data collected by the IMS have a strong potential to contribute to sustainable social and economic development and yield compelling civil and scientific benefits. These benefits can contribute to the achievement of the SDGs adopted by the United Nations in 2015. While the narrative on stronger linkages between disarmament and development remains one of the least explored, the CTBTO has a powerful toolkit to contribute to both these objectives.

The CTBTO addresses the threat of nuclear explosion and, on a larger scale, aims at building a peaceful and secure international environment (SDG 16), which is a precondition for the implementation of the SDGs. Thanks to its monitoring system, the CTBTO can play a facilitating role in attaining the SDGs, particularly on issues related to climate action (SDG 13), with the use of its data, and disaster risk reduction, with early warning systems. To do so, more political will from States Signatories is needed.

In terms of next steps, it was noted that the CTBTO should develop even more relationships with research organizations, civil society, governments and United Nations organizations, especially in developing countries. The CTBTO may also wish to consider strengthening the link between the High Level Political Forum on the SDGs and its activities to promote the entry into force of the CTBT. In addition, the links between the work of the CTBTO and the achievement of SDGs should be made more visible. Although the CTBTO is already a strong advocate for gender parity and women's involvement in science, as evidenced by its outreach and training activities, it should further contribute to gender equality (SDG 5) in this field.

4.9. Highlight Talks: Knowledge of the Geosphere Structure and Dynamics – Knowledge Gained from 20 Years of the CTBT

Elisabeth Blanc introducing the Highlight Talk on Structure and Dynamics of the Atmosphere.

The three Highlight Talks focused on recent scientific advances in various aspects of the structure and dynamics of the atmosphere, the solid earth and the ocean, which constitute the geosphere. Topics particularly relevant to the CTBTO are the core of verification sciences. As such, the Highlight Talks related to the detection of nuclear tests and in particular the challenges in detection, characterization and location of events emerging in the complex geosphere. The main question addressed by the speakers was whether we have learned and gained knowledge from 20 years of the CTBT through the operation of the IMS and the production of IDC products.

Michel Jean delivering the speech on Structure and Dynamics of the Atmosphere.

Highlight Talk 1: Structure and Dynamics of the Atmosphere

Highlights

An enlightening presentation on progress in numerical weather prediction modelling over the last few decades was provided. The continuous increase in computational power and more sophisticated modelling will generate a tremendous amount of data. This in turn will lead to the accelerated development of artificial intelligence to deal with the data generated every day.

There is already a large amount of data available to the CTBTO for more enhanced atmospheric and oceanic transport modelling. Whereas the sole interest of the CTBTO is the use of these models to support its verification mandate, data from infrasound stations of the CTBTO can also help numerical weather prediction centres produce more accurate analyses and forecasts. However, there is a challenge in identifying where the data are being held and how to deal with large data sets. This trend will grow in the future and will also encompass global data processing and forecasting systems. The issue for the CTBTO will be to identify what data will support the verification regime.

Tarje Nissen-Meyer delivering the speech on Structure and Dynamics of the Solid Earth.

Highlight Talk 2: Structure and Dynamics of the Solid Earth

Alik Ismail-Zadeh introducing the Highlight Talk on Structure and Dynamics of the Solid Earth.

Highlights

This presentation underlined the fact that the collection of large data sets is increasing. It recognized that the value of the data is in combining them. There is currently no other system like the CTBTO verification system that can acquire, analyse and use data. However, relatively few scientists are aware of IMS data and IDC products, and even fewer have access to it. Broader use of CTBTO data in other applications and the application of different algorithms and analysis techniques to CTBTO data will increase the likelihood of new methods being developed that will also benefit the verification system.

Waveform data is complex, and to reach a point where it can be effectively used to distinguish between different sources will require the collective output of as many researchers as possible. The benefits of artificial intelligence, in particular to speed up the processing of 3-D wave propagation, was a key element of this discussion.

Highlight Talk 3: Structure and Dynamics of the Ocean

Yoshiyuki Kaneda introducing the Highlight Talk on Structure and Dynamics of the Ocean.

Highlights

Acoustic propagation in the ocean is the result of how the ocean is structured. Ocean sound is an essential ocean variable, and the CTBTO is an important contributor to its observation through the 11 hydroacoustic stations of the IMS.

Hanne Sagen delivering the speech on Structure and Dynamics of the Ocean.

Sub-surface temperature is an also an essential ocean variable, and the hydroacoustic stations of the CTBTO contribute to knowledge on the mean ocean temperature. This data can become a significant contributor to assessing the impacts of ocean warming on marine ecosystems.

4.10. Scientific Applications: Science of Climate Change with CTBT Technologies

Rebecca Manzou, Hanne Sagen, Jean Sciare, Lucrezia Terzi and Matti Goldberg at the panel discussion on Scientific Applications: Science of Climate Change with CTBT Technologies, moderated by Tammy Taylor.

The panel focused on the use of CTBT technologies (and respective IMS data and IDC products) in support of climate change sciences. The panel discussed the status of the science in climate change research, how CTBT technologies and IMS data can support the monitoring of climate change, and how cooperation with other organizations can help to achieve global climate change goals.

Highlights

The panellists shared observations and experience on the effects of climate change in critical geographical areas. They noted that continuous monitoring of climate change is essential and that better climate monitoring and projections are needed. CTBTO technologies and data can play a key role in this. 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 United Nations SDGs.

Evidence of climate change and its negative impact on rural areas in Zimbabwe, whose economy is agriculture based, were discussed, as well as the importance of better seasonal forecasts for the onset of monsoons. Some studies on climate change patterns have been performed using detections of the natural radionuclide ^{7}Be measured by the CTBTO radionuclide network. Be-7 detection trends can be applied to civil use for monsoon prediction: tropopause heightening and slowdown of circulation have strong agricultural impacts, such as increases in storm frequency and extended warm periods/drought that can be quantified. Monsoon prediction using ^{7}Be concentrations is an improvement compared with traditional methods, as predictions with ^{7}Be can be performed 52 days in advance (compared with 7-21 days for traditional methods), with an accuracy of three days (compared with five days for traditional methods).

The Arctic region is a key area for monitoring global climate change. Massive changes have been observed, including warmer surface temperature, loss of sea ice, warmer oceans, melting of the Greenland ice sheet and thawing of permafrost. The major consequences of these changes on the regional and global scales are mainly related to changes in ocean circulation, increased sea level, changes in marine biodiversity, increased seismicity and potential geo-hazards. In order to improve climate projections there is a need to combine different observation systems with models. More data would be necessary to better understand the climate system and validate modelling results. CTBTO seismic and hydroacoustic stations are excellent technologies, providing a continuous stream of data in real time. Combining these technologies with pressure sensors, temperature sensors and current meters would further improve monitoring.

The Eastern Mediterranean and Middle East region is one of the major climate change hotspots in the world, with obvious social, economic and political impacts. Different monitoring networks and infrastructures are in place for atmospheric science, including the Integrated Carbon Observation System (greenhouse gases), the Aerosol, Clouds and Trace Gases Research Infrastructure (aerosol/clouds/reactive gases), the Network for the Detection of Atmospheric Composition Change (remote sensing) and the World Radiation Monitoring Center/Baseline Surface Radiation Network (solar radiation). However, there is a gap in observational data in this geographical area that may be filled by CTBT technologies.

The United Nations system plays a central role in the area of climate change through some legal instruments such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, bringing together global resources for observation and analysis of climate change trends, and provides a forum to take collective action on climate change. UNFCCC helps governments of the world to negotiate a set of global instruments for dealing with climate change. The Paris Agreement aims to integrate the best available scientific knowledge with the UNFCCC policymaking process. Potential agreements and cooperation may be further discussed to get UNFCCC and CTBTO to work more closely together.

4.11. Science Diplomacy: Science Advisors and Arms Control Practice – Improving Policy Implementation Through Technical Expertise

Ted Bowyer presenting Backgrounds, False Negatives and False Positives: Dealing with Radionuclide Detection in 2019 (T2.4-011).

The discussion focused on the steps that have been taken to inform the implementation by States of non-proliferation and disarmament instruments through scientific and technical advice and considered how such advice can assist States in reaching conclusions regarding CTBT-relevant areas.

Jonathan Forman, Peng Li, Mosa Mabuza and Man-Sung Yim speaking at the panel discussion on Science Diplomacy: Science Advisors and Arms Control Practice – Improving Policy Implementation through Technical Expertise, moderated by Mahlet Mesfin.

Highlights

Science is a fulcrum for policy development. The issue is how to provide access to good scientific advice, especially in developing countries, and how to encourage policymakers to see such advice as beneficial. Capacity development in science advice can first focus on economic development and environmental issues and in time be used for further matters, such as arms control.

Keeping abreast of technological developments is important for arms control. Examples include constant innovation in areas such as satellite navigation, which is increasingly developed in national or bloc silos. Scientific collaboration across countries can help find common platforms that are more effective and can be used for matters of common concern.

Bridging the gaps between the scientific community and diplomats can help both. In particular, this can help build trust needed to make progress on arms control. Science diplomacy is also an entire ecosystem that provides links to academia, non-profit organizations and industry. Working Group B of the CTBTO is a good example of a forum in which scientists and diplomats mix for mutual benefit.

4.12. Getting the Non-Proliferation and Disarmament Architecture Back on Track

Lord Desmond Henry Browne introducing the panel discussion on Getting the Non-Proliferation and Disarmament Architecture Back on Track.

Ahead of the 2020 NPT Review Conference, this panel examined the prospects for forging consensus on nuclear non-proliferation and disarmament and asked what role the CTBT and its verification regime can play in establishing common ground.

Looking ahead, other issues that need to be considered are the potential role of the CTBT in the denuclearization of the Korean Peninsula, the implementation of United Nations Security Council Resolution 2310 on the CTBT, and the emergence of new approaches to nuclear non-proliferation and disarmament.

Ambassador Alicia Buenrostro Massieu, Ignacio Cartagena Núñez, Ambassador Rafael Grossi and Ivan Timofeev speaking at the panel discussion on Getting the Non-Proliferation and Disarmament Architecture Back on Track, moderated by Tariq Rauf.

Highlights

The links between the CTBT and the NPT are clear. The CTBT emerged from the NPT process, and the association remains. The current atmosphere is not favourable to the development of new instruments in nuclear non-proliferation, so the international community must preserve and deliver on those it has, such as the CTBT. Many countries consider the CTBT as a litmus test for progress on disarmament.

Non-proliferation and disarmament requires the particular engagement of the nuclear weapon States. At present there are different approaches among these countries. Dialogue between the United States of America and the Russian Federation is particularly lacking and will be crucial if the architecture is to be sustained. 'Toxic topics' outside of nuclear weapons have affected the atmosphere in a negative way. The way forward is to concentrate on the institutions and instruments that exist and preserve them.

The 2020 NPT Review Conference will be challenging, but the NPT itself is resilient. The strong link between the CTBT and NPT must be emphasized at the Review Conference.

4.13. Civil Applications: The Use of CTBT IMS Data in Support of Disaster Risk Mitigation

Elisabeth Blanc, Laura Kong, Ricardo Mena, Steven Pawson and Juan Carlos Villagran speaking at the panel discussion on Civil Applications: The use of CTBT IMS Data in Support of Disaster Risk Mitigation, moderated by Bruce Howe.

Civil and scientific applications benefit greatly from data acquired from the IMS. These data are primarily recorded with the purpose of monitoring the world for signs of nuclear explosions. The discussion focused on the contribution of such data to global disaster mitigation of naturally occurring hazards and to global sustainment development goals as outlined in the 2030 Agenda for Sustainable Development, the Paris Agreement on climate change and the Sendai Framework for Disaster Risk Reduction 2015-2030, e.g. tsunamis, volcano eruption, ocean monitoring, radioactive emissions, etc.

Highlights

The international community of disaster risk reduction recognizes the exceptional monitoring capabilities of the IMS, which allows a global view of many relevant phenomena by providing data that is of high quality, continuous and reliable, with low latency access. The system provides signals from fractions of seconds (e.g. earthquakes, tsunamis, volcanos) to decades (e.g. ocean soundscape, climate).

It was agreed that the approach to disaster risk reduction should be holistic, including data management and flow to users, data fusion (e.g. using different data types in data assimilating models), and liaising between organizations, early warning systems and national authorities. This would ultimately result in effective products that would motivate vulnerable populations and people to take action.

The CTBTO mission specific training and capacity building for States Signatories and especially for developing countries was acknowledged. In addition to fulfilling CTBT tasks, such training allows local staff to further exploit the data for multi-hazard disaster risk assessment, early warning and emergency response. However, at the user end, it was recognized that more effort at the national level is required to document and optimize usage of CTBTO data in addressing hazards.

Participants took note of the fact that one of the global targets of the Sendai Framework for Disaster Risk Reduction 2015-2030, the global plan to reduce disaster risk that was adopted by the United Nations Member States in 2015, is to substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessment to people by 2030.

The United Nations Office for Disaster Risk Reduction (UNDRR) has expressed interest in liaising with the CTBTO, as it recognizes the potential value of CTBTO data to disaster risk reduction. UNDRR is responsible for supporting and monitoring the implementation of the Sendai Framework.

4.14. vDEC Briefings: Experience in Using CTBT IMS Data for Scientific Applications

The briefings focused on vDEC success stories with the experience of using IMS data and IDC products for scientific studies related to different technologies. The briefings provided an overview of a variety of projects that have been carried out since the establishment of vDEC in 2011.

Rodrigo de Negri, So-Gu Kim, Won-Young Kim, Wolfango Plastino, Dirk Metz and Tracey Rogers speaking at the vDEC briefing on Experience in Using CTBT IMS Data for Scientific Applications, moderated by Jolanta Kusmierczyk-Michulec.

Highlights

Participants shared their experience in using CTBTO data and products through vDEC, including the use of hydroacoustic data to study how whale populations are influenced by changes in the marine environment; hydrophone data to study submarine volcanic activity; infrasound data to improve the monitoring capabilities of volcanic eruptions in Chile; regional seismic data to study earthquakes in stable continental regions; seismic data to determine a value of depth for the nuclear tests by the Democratic People's Republic of Korea; and radionuclide data to analyse time series of xenon, radon and ^{7}Be.

4.15. DPRK Nuclear Testing: CTBTO Expertise and Knowledge

Jeffery Lewis, Paul Richards, Petra Seibert, Vitaly Shchukin and Brian Stump speaking at the panel discussion on Democratic People's Republic of Korea Nuclear Testing: CTBTO Expertise and Knowledge, moderated by Tammy Taylor and Anders Ringbom.

The panel discussed new scientific and technical information obtained from six nuclear tests by the Democratic People's Republic of Korea and their aftershocks within the framework of theoretical and empirical knowledge related to underground nuclear testing in the past. The IMS detection capabilities and detection/event characterization/screening methods used by the IDC were tested in real time and conditions, proving principal concepts of nuclear test monitoring.

Highlights

The panelists agreed that waveform analyses of the announced nuclear tests by the Democratic People's Republic of Korea further raised confidence in the monitoring capabilities of the IMS. The precise location has reached high agreement among experts, and the error ellipse is small enough to define the area for OSI that is limited to a maximum of 1000 m^2. New methods of seismic analysis based of waveform cross-correlation demonstrate the possibility to improve event location by two orders of magnitude and find much smaller events. When augmented with synthetic aperture radar (SAR) interferometry calculated from satellite data, the seismic locations were confirmed and the possible inspection area could be further confined.

Seismic and infrasound waves measured from the six nuclear tests by the Democratic People's Republic of Korea demonstrated that processes in the vicinity of an explosion and the source function of underground nuclear explosions are well, but not fully, understood and can be modelled only with relatively large uncertainty. Further investigations are needed to improve the monitoring capability of the IMS specifically with regard to special parameters such as focal mechanism.

A common understanding was expressed that the transport of noble gas in the atmosphere is much more complicated than it was estimated before the tests by the Democratic People's Republic of Korea. In order to address this complexity, enhanced methods need to be developed. To validate these methods, more experimental data with noble gas systems are needed. These systems should be located in configurations that offer observational data that are suitable for a scientifically robust validation.

Radioxenon signals were associated soon after their detection with only two out of six nuclear tests announced by the Democratic People's Republic of Korea. It remains to be seen whether radioactivity from the other four tests was fully contained, stayed below the detection threshold of the IMS systems or did cause signals at IMS noble gas systems that remain hidden in the highly variable background. The isotopic ratios observed in the test of 2013 can only be understood with specific assumptions about the release scenario. These aspects highlight the need to conduct studies on appropriate radionuclide source term estimates. It should be noted that the IMS system is fully functional even in the absence of reliable radionuclide signals. Nevertheless, OSI is the crucial approach for a definite CTBT verification.

Interaction between the expert community and professional organizations with various social groups and the media has become an important issue because of the increasing influence of processes with possible positive (e.g. crowd sourcing) or negative (e.g. distribution of false information among millions of readers) impacts on the monitoring regime and on the societal perception of technical experts and organizations.

4.16. What Kind of Improvement Can Artificial Intelligence Bring to the Work of the CTBTO?

Stuart Russell, Korhan U. Şemi and Kardi Teknomo speaking at the panel discussion on What Kind of Improvement can Artificial Intelligence Bring to the Work of the CTBTO? Moderated by Megan Slinkard.

The objective of this panel discussion was to inform the audience about the use of artificial intelligence by the CTBTO and the potential use of the latest developments in the field. What are the artificial intelligence methods that can facilitate finding the needle in the haystack?

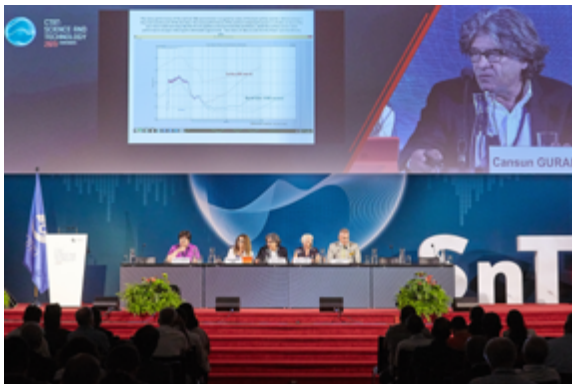
Highlights

Even though IDC processing has been an early adopter of artificial intelligence methods such as neural networks and Bayesian methods for seismic phase identification, new developments in the field merit further consideration as a means to improve the data processing system of the IDC. One idea that dates back to 2009 is to explore further applications of the Bayesian method beyond the NET-VISA (Network Processing Vertically Integrated Seismic Association) software that is currently used operationally at the IDC. NET-VISA uses parametric data in the form of detections to produce bulletins. The new method SIG-VISA (Signal-Based Vertically Integrated Seismic Association), which infers bulletins directly from waveforms, has been investigated. It was noted that considerable progress has been made with the production of a PhD thesis and publications about this new method. Another aspect of the Bayesian framework is that it is particularly suitable for the incorporation of complex physical modelling and may be the next practical step the CTBTO could take in improving its processing system, for instance by using accurate three-dimensional modelling of seismic, hydroacoustic or infrasound propagation.

The Ideal Flow Network method is a way to combine different machine learning tools, including semi-supervised learning and feature selection, and may be a promising integration tool to tackle the detection, location and characterization of CTBT-relevant events. In order to progress and assess any benefits that may stem from such a method, a proof of concept test with real data should be undertaken.

One of the remaining challenges in the current IDC system is the processing of large aftershock sequences. IDC analysts have requested improvements to tackle this issue, as the quality of the automatic bulletins degrades during such sequences, making their work more challenging. Combining traditional methods such as match filters and cross-correlation methods with artificial intelligence should be investigated.

4.17. Where Do You See the IMS Monitoring Technologies Evolving for Enhanced Capability?



Naila Babiker, Roberto Betancourt Arocha, Valerie Flavin, Cansun Guralp and Noriko Kayama speaking at the panel discussion on Where do you see the IMS Monitoring Technologies Evolving for Enhanced Capability? Moderated by Nurcan Meral Özel.

The IMS sensor network has already demonstrated the capability to detect nuclear tests. However, it is still important that the monitoring technologies evolve and keep abreast of current developments and desired capabilities. This panel focused on innovations and advancements of monitoring technologies to improve the performance of the IMS network.

Highlights

Panellists highlighted the reliability and neutrality of the organization and noted that the IMS technologies are working well and that the information provided is very useful.

It was observed that more than 20 years have passed since the IMS was first established. The monitoring system benefits from new technology developments through upgrades and system replacement when the life cycle of the old systems has come to an end. Converting surface seismic sensors to borehole stations to reduce background noise and the possibility of using a new type of borehole sensors as well as gimbaled sensors should be considered.

Artificial intelligence and deep learning methods could reduce the burden placed on IDC analysts, and if these enhanced analysis methods are shared with National Data Centres, it would also benefit the States Signatories. NDCs can refine the event analysis based on IMS data with data from other worldwide seismic networks and national networks. In-depth analysis using artificial intelligence would reduce the cost of on-site inspections. Using SAR interferometry calculated from satellite data would provide detailed information on crustal deformation in the inspection area.

The panellists discussed various opportunities for further enhancing the efficiency of the IMS. Availability of spare parts and obsolescence management could be improved. Using general equipment and systems for communications and analysis rather than customized systems could reduce operation and maintenance costs.

4.18. Fishbowl Discussion: Reducing Uncertainty in Sensor Networks

The fishbowl discussion encouraged audience participation.

The essence of the 'fishbowl discussion' was to inspire discussion topics that address the ability to apply smarter, automated algorithms to establish a noise floor with a minimum credible event detection by using various populations/sources of sampled data. All of this should increase the ability of the IMS network to automatically flag, detect, analyse and characterize events, as well as establish IMS thresholds. The audience was encouraged to contribute actively to this discussion.

Sergio Barrientos moderating the fishbowl discussion on Reducing Uncertainty in Sensor Network.

Highlights

Sensor maintenance, relocation and replacement all affect operator confidence and uncertainty considerations. This is true for all phenomenologies relevant to the CTBTO mission: radionuclide, hydroacoustic, infrasound and seismic. Improved advance coordination and timely notification of these activities for sensor systems managed by the PTS may result in improved operator understanding and confidence as well as reduced uncertainty in sensor detections.

Uncertainties develop from many mechanisms in the path from signal generation to analysis, including signal initiation and propagation, sensor performance and processing, modelling, and analysis. In addition, uncertainty also arises in the art/science of weaving together all of the process/informational products towards the creation of the final determination. A relevant forward path is to help identify and reduce these sources of uncertainty by fully understanding the integration of the processes and reducing modelling transitions. This is particularly true in meteorology (atmospheric modelling).

CTBTO infrasound efforts over the last several years have resulted in the discussion and adoption by the International System of Weights and Measures of a primary infrasound standard and metrology. It was recommended that action be taken by the CTBTO to establish a similar standard for seismological systems.

4.19. Civil Applications: Towards Monitoring Near Earth Objects Impacting the Atmosphere

Panel discussion on the use of CTBT IMS Data in Support of Disaster Risk Mitigation.

Near earth objects (NEOs) represent potentially catastrophic threats to our planet. Addressing such hazards, including identifying objects that pose a risk of impact, planning mitigation campaigns and monitoring actual atmospheric impacts with observation networks potentially complemented by IMS infrasound data, requires global cooperative action in the interest of public safety.

Highlights

The panel demonstrated that NEOs represent catastrophic threats to the earth. Current operational systems attempt to identify objects that pose a risk of impact. The civil and scientific space communities are planning mitigation solutions, which require the monitoring of atmospheric impacts with a variety of observation networks. Recent studies demonstrate that IMS infrasound data is useful to better monitor and understand fireball population and thus support the mitigation efforts. The case of the bolide over the Bering Sea in December 2018 illustrates this. Access to real time infrasound data would contribute in a beneficial way to existing systems as a complementary means of observation. Global planetary defence cooperation is taking shape in the interest of public safety.

4.20. Threats of Tomorrow: Use of Artificial Intelligence and Machine Learning in Predicting and Responding to Malware

Leesa Carson, Timo Mischitz, Bojan Smetic, Emily Taylor and Neil Walsh at the panel discussion on Threats of Tomorrow: Use of Artificial Intelligence and Machine Learning in Predicting and Responding to Malware.

The objective of this panel discussion was to discuss current trends in artificial intelligence and machine learning with a focus on potential security threats associated with these technologies. Presentations on shared threat intelligence and cloud computing were offered by some panellists and served as the basis of discussions.

Highlights

The migration of the Australian (waveform) National Data Centre into the cloud and the security implications of this move were discussed. Security and operability had improved, while operational costs had been reduced.

It was uniformly agreed by the panel that artificial intelligence and machine learning are needed in cyber security, as threats are coming faster and thicker than a human can respond. By the time a threat has been detected, it may already be too late to respond. Past modalities, e.g. using static virus signatures, are no longer sufficient, and the speed and intensity of attacks will only increase.

Organizations like the CTBTO struggle to keep up and will likely continue to be consumers of these technologies only through turnkey security appliances and outsourced security services (e.g. Common Secure via United Nations International Computing Centre). In-house expertise is still required to liaise between external services and internal users.

It was noted that organizations will increasingly need to plan on keeping digital evidence of attempted intrusions or attacks for forensic and legal purposes.

4.21. On-Site Inspections Triggered by Events in Complex, Dynamic or Challenging Environments

Vitaly Shchukin speaking at the panel discussion on On-Site Inspections Triggered by Events in Complex, Dynamic or Challenging Environments.

The panel discussed the scientific, technical, operational and legal aspects of conducting on-site inspections in extreme environmental conditions and on the high seas in areas beyond the national jurisdiction and control of any State.

John Walker moderating the panel discussion on On-Site Inspections Triggered by Events in Complex, Dynamic or Challenging Environments.

Highlights

The panel concluded that OSIs addressing underwater nuclear tests could be better supported through the development of dedicated water column radionuclide and thermal transport modelling and through modelling of the likely acoustic signatures of underwater nuclear test scenarios. Mobilization timescales both on land and at sea remain a challenge; therefore approaches such as pre-negotiated standing arrangements for inspection equipment rental contracts would help, noting that the holding of all likely required equipment by the CTBTO was not feasible given the wide range of possible OSI scenarios. Timely access to major assets such as appropriate ships should also be further explored. Given the challenging environmental conditions that inspectors will encounter, inspection planning needs to consider the human factor and address the number and skills of available inspectors. To help future planning, further development of concepts of operation for OSIs in challenging environments both on land and at sea should be undertaken.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Nurcan ÖZEL
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CLOSING SESSION
AND AWARD CEREMONY
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TOGETHER


Lassina ZERBO

5. Closing

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

CTBTO Executive Secretary Lassina Zerbo delivering closing remarks.

Excellencies,
Ladies and Gentlemen,

It's hard to believe that we have reached the end of CTBT: Science and Technology 2019. There has been so much behind the scenes work by so many people that SnT has seemed a constant fixture in CTBTO life for much of the last year.

During my opening address on Monday I mentioned with gratitude the Project Executives and Project Managers who have led this process, and to this I wish to add my heartfelt thanks to the entire team throughout the whole organization. From planning the programme, to negotiating the contracts, to liaising with participants, to promoting the conference, this was a titanic task, especially when you consider that the staff members involved were doing this alongside their regular duties.

I'm sure all will agree it was well worth it. SnT has been our flagship conference for some time, and this year that is more obvious than ever. Participation figures have grown immensely. I was delighted to see the high turnout for panels and scientific sessions throughout the week, at all times of day, and even at night!

I will leave it to the Project Executives and to two members of the Scientific Programme Committee, Dr Zeinabou Mindaoudou Souley and Professor Paul Richards, to sum up the conference in detail, however to me this high level of interest demonstrates the value that the scientific and policymaking communities see in SnT.

Following these final reflections and summaries, we will have an awards ceremony for the best one minute poster presentation (what we call the Science Slam), the best poster presentation, the best oral presentation and the best presentation by a young scientist. I would like to thank each and every person who submitted an abstract for consideration. The effort you have put in is well appreciated. We will then close the session, and the SnT2019 conference, with the EU Star Award, to be presented by Mr Tobias Krause, Deputy Permanent Representative of the European Union.

On Monday, I appealed for us all to overcome cynicism where nuclear non-proliferation and disarmament is concerned. After a week like this, it is hard to be cynical. Session after session has borne out the fact that CTBT technologies and CTBT data are delivering. The community of scientists present here from all parts of the world are enthused. This is a global public good that we cannot afford to give up.

Likewise, we have heard from policymakers this week that the CTBT has to be part of the package if we are to achieve peace and security. The institutions and instruments we have, and that are working well, need to be preserved. In fact, they need to be cherished. They are the essential building blocks on which trust can be built.

As ever, young people have been out in force at SnT. I wish to end my remarks by thanking the younger generation of participants, from the CTBTO Youth Group to the young scientists. You have been fuelling the conference with your enthusiasm, whether it is preparing the *SnTimes* publication or demonstrating how the CTBT can help deliver the United Nations Sustainable Development Goals.

I must give a special mention to perhaps the youngest conference participant of all: four year old Leung Hon Yin from Hong Kong, China, who was an award winner at yesterday's Youth Art Competition. It is young people like him who will need to do the heavy lifting in the future unless we act to rebuild trust.

So thank you all for being a part of SnT2019, and please welcome the Project Executives, Nurcan Meral Özel and Tammy Taylor.

5.2. Tammy Taylor, SnT2019 Project Executive, Director of the International Data Centre Division, CTBTO

Tammy Taylor, Director of the International Data Centre Division.

Dear Ladies and Gentlemen,
Friends and Colleagues,

I cannot help but start off with all of the thank you messages. Firstly, I would like to thank all of you. I received a lot of questions this week about how we did it and how we were able to gain so many more participants. It is because of all of you. You are so interested in the work we are doing and we are so very grateful for your participation and your support. Thank you for the excellent presentations and panel discussions. I am very grateful for all of them.

The Local Organizing Committee has met every single week since my arrival 10 months ago. It is inspiring to see how they have been moving parts and pieces for almost two years to bring this event together. Nearly every CTBTO staff member contributed in some way, shape or form. I would like to acknowledge our Policy Making Organ Secretariat Support Section, our Procurement team, the Project Officers of the International Data Centre Division and the International Monitoring System Division, and our administrators who made all the travel arrangements for all of the sponsored travellers. The IDC took on a huge leadership role with Pierrick Mialle conducting our Scientific Programme, Peter Nielsen taking on the panel leadership and organizing 19 panels, Gerard Rambolamanana and Waseem Allan leading the capacity building activities and the arrangement of all of the travel and the special side events, our Scientific Programme Committee members, and our Project Managers Martin Kalinowski and Jim Mattila, who were mentioned already. Martin and Jim are such an inspiration and exceptional leaders. Any time I would walk in worried about how we could solve a certain problem Martin would reassure me by saying "Oh no, this will be easy". Jim, this is your last day with the Provisional Technical Secretariat and we will miss you. Thank you for your service.

Nurcan, my co-Project Executive, we have worked so closely together over the past months and have become like sisters now. We will have to find new things to bond over in the coming months ahead. Thank you for the vision and inspiration of our esteemed leader Dr Lassina Zerbo.

I could go on and on about the science behind this meeting and all the things that I personally was able to pick up, but I will leave this to our two Scientific Programme Committee representatives, Dr Zeinabou Mindaoudou Souleye and Dr Paul Richards.

I commit to you a timely SnT2019 Summary Report that we can all benefit from in terms of follow-up, collaboration and furthering the progress of our scientific and civil data application purposes.

I would like to share some personal reflections of significance in three areas, which are artwork at the interface of science, youth as global citizens and finally women in science, technology, engineering and

mathematics (STEM). Many of you have shared with me the significance of your emotions during the sand art experience on Monday when Irina Titova dazzled us with her talent. You may have also experienced the Youth Art Competition entries in our lounge and the awards ceremony yesterday. For me, this conference has solidified the importance of our mission to people all over the world. How worthy it is for this work to be understood by global communities. Art provides a vehicle to deliver the message of our mission to non-technical communities and it should provide a vehicle back to us for the artists and the children to convey to us as decision makers and technical experts the importance and significance of what they desire for our future, their vision for our world.

To our CTBTO Youth Group members, you inspire me. I am grateful for your courage and your expertise. You have much more to teach me than I have to teach you. Do not lose your resolve to finish what we started. Seeing briefs on the United Nations Sustainable Development Goals from presenters and collaborators whose home countries are in political strain with one another was absolutely refreshing and gave me hope. Thank you!

Finally, the women's panel, which occurred on Monday night and became somewhat of a theme for us for the entire week, was a personal highlight for me. I am hopeful that we are finally beginning to understand how to approach equality in the technical workplace. Leaders, my plea to you is that you insist on strong technical experts who represent the diversity you seek when you form your hiring pool. Recruiting to simply get women in the pool who cannot compete with men should not be tolerated. There are technically competent women who can compete. Please find them. We must provide what women have to offer to this mission and to science and technology.

Thank you all very much.

5.3. Nurcan Meral Özel, SnT2019 Project Executive, Director of the International Monitoring System Division, CTBTO

Nurcan Meral Özel, Director of the International Monitoring System Division.

Excellencies,
Ambassadors,
Dear Colleagues,

Let me start by thanking the esteemed Dr Lassina Zerbo for his leadership, vision and guidance in making the fifth CTBT: Science and Technology conference the biggest one in the history of the CTBTO. I believe this exceptional vision of the Executive Secretary derives from his scientific background.

I want to express my gratitude to my co-Project Executive Tammy Taylor and our excellent Project Managers Dr James Mattila and Dr Martin Kalinowski. This was James's last SnT and his farewell contribution to the CTBTO. James is returning home next week. We will miss his leadership of the Engineering and Development Section of the International Monitoring System Division. Thank you, James Mattila, for all the effort you made for the CTBTO and for SnT. Last but not least, I am grateful for the efforts of the dedicated CTBTO staff and their contribution since 2018. They worked tirelessly to make this conference a success.

SnT2019 was a very successful conference, with a variety of participants and panels, scientific abstracts and posters exceeding all previous SnT conferences. Our aim of surpassing the bar set by SnT2019 will be more challenging and difficult the next time in 2021.

There are three outcomes that I would like to note in particular. First, the conference reinforced the popularity and importance of the CTBTO and its technologies and its outlook to science for the verification of nuclear non-proliferation and disarmament and above all peace. There has always been a close link between scientific expertise and efforts towards building peace and security. This conference underlined once again this shared internationally acknowledged value.

Second, we agreed that increased participation by civil society, particularly women and youth, in science, technology, engineering and mathematics (STEM) fields is needed. Third, the conference provided a unique opportunity for scientists from all over the world to interact with relevant industry leaders and policymakers and make invaluable exchanges on the civil and scientific applications of the CTBTO's wide spectrum of technologies. This unique fusion of science, policymaking and academia will contribute to progress towards the CTBT's entry into force and the United Nations Sustainable Development Goals.

Personally speaking, in my area of responsibility I have received a lot of positive feedback on the IMS technologies and instrumentation. My observation is that big progress has been made in the usage of IMS data by many different stakeholders. I would especially like to see more common usage of data among scientists. We had fantastic discussions during the IMS panel and we were informed about new evolving verification and monitoring technologies. As the Director of the IMS Division, I would like more attention to be given to scientific advances and new technologies and IMS data usage. The participants presented cutting edge technologies and innovations and suggested ways the CTBTO and especially the IMS can maintain value for money, optimize and keep abreast of technological developments. We saw excellent research abstracts and posters and many encouraging examples and success stories during this conference.

I would like to express my appreciation particularly to the presenters and vendors for their innovative instruments that will be very useful to bringing the IMS network into the future. For the first time, the IMS hosted an exhibition of its instruments. I hope you have also benefitted from the exhibitions and projects of the IMS Division. I would especially like to thank my staff for presenting all IMS projects and scientific contributions to SnT2019.

To end, I would like to once again share my heartfelt congratulations to all of the awardees.

I thank all participants, from governments to the CTBTO Youth Group, for their active engagement in SnT2019 and hope to carry this work and the outcomes of this conference forward with the IMS and all of the CTBTO.

We have always been delighted to receive feedback, and I have received a lot of constructive criticism concerning panel contents, timing of the events, posters, policy issues and women's participation. We will take it all into account and will make SnT2021 even better in the light of all your feedback.

I would like to conclude by saying that I am extremely pleased and honoured to have been here with you, distinguished scientists, technology experts, policymakers, students and friends from all around the globe, for the last five days. I had a chance to discuss many areas of scientific research, new projects and technological advancements, especially on instrument issues. You took me back to my academic life.

Thank you.

5.4. Zeinabou Mindaoudou Souley (Niger), Special Advisor to the President of the Republic of Niger, Chair of the High Authority for Atomic Energy of Niger, Vice-Chairperson of Working Group B

Zeinabou Mindaoudou Souley, Special Advisor to the President of the Republic of Niger.

I am honoured by the request made to me to share my thoughts on this conference. I thank the Executive Secretary, Dr Lassina Zerbo, and his entire staff for this opportunity. I am pleased to say that the CTBT: Science and Technology 2019 conference provided a platform for inter-communal and interregional exchanges. Scientists, diplomats, journalists, manufacturers, technicians, artists, young people, journalists and men and women from different parts of the world were able to plan and discuss future projects concerning science and technology.

The primary objective of the International Monitoring System that was established by the CTBTO is the detection of nuclear tests. However, the available facilities and collected data substantially contribute to the fulfillment of the United Nations Sustainable Development Goals. This is an especially interesting aspect for developing countries, which, provided that their involvement in CTBTO activities is more dynamic, could contribute tremendously to the implementation of the Treaty. Development requires a safe and secure environment. Therefore the CTBTO must be at the forefront when it comes to the global implementation of the SDGs given their crucial role in global security. Beyond that, the data collected by the IMS can help convince governments that there are non-Treaty uses that can directly impact people's lives and priority areas for sustainable development.

The vDEC panel taught us about different experiences through the usage of IMS data for scientific applications, such as hydroacoustic data to study changes in the marine environment and its impact on whale populations, IMS hydrophones to monitor submarine volcanic activity, infrasound data to improve the monitoring of volcanic eruptions, seismic data to study earthquakes in stable continental regions and to determine nuclear testing and radionuclide data to analyse time series of noble gases, to name a few examples. The presentations and discussions during this conference clearly show that greater efforts on several levels need to be made in terms of communication. Scientists need to be involved more strongly in order to explain how certain scientific activities directly impact national priorities. Every country can use the collected data for their individual purposes, such as strengthening the participation of women and youth and using social networks to reach larger groups of people. These objectives can of course only be achieved through the implementation of an appropriate capacity development programme.

Data collected by radionuclide stations with particulate and noble gas systems can be used to monitor nuclear explosions, to verify tests that occurred in the past and to evaluate natural radionuclides and those issued by nuclear accidents and research reactors. Weather forecasting, atmospheric modelling and climate change mitigation were considered in presentations and posters under the themes "The Earth as a Complex System" and "Atmospheric Dynamics", which discussed among other subjects the application of advanced data assimilation techniques to improve atmospheric transport and dispersion forecasts, the evaluation of the meteorological models of the middle atmosphere using lidar and noise and the atmospheric boundary layer used as a laboratory for modelling the propagation and diffusion of infrasound in the atmosphere.

Other matters that were discussed included the data collected by the CTBTO that are currently being used and also considered for future applications in order to combat climate change and how cooperation with other organizations, such as the United Nations Framework Convention on Climate Change and the Paris Agreement, can aid in achieving the SDGs.

Further topics included the evidence of climate change and its negative impact on rural areas, the importance of improved seasonal forecasts for the onset of monsoons and observations made in the Arctic region, which acts as a key area when it comes to monitoring global climate change.

The topic "Atmospheric and Subsurface Radionuclide Background and Dispersion", with 57 posters and 11 high level scientific presentations, dealt with the usage of radionuclide data from particulate and noble gas systems to analyse radioxenon releases, the evaluation of natural radionuclides in the air, the assessment of atmospheric dispersion of radionuclides resulting from the Fukushima accident, the monitoring of the global inventory of radioxenon emissions by research reactors, the collection of data for the production of ^{99}Mo by fission and to search for radioxenon signals associated with the announced nuclear tests by the Democratic People's Republic of Korea.

Discussions of historical monitoring data also talked about the release of noble gas after underground nuclear explosions as well as from laboratories and mobile and field based facilities. Three oral presentations were held in which the SnT community was encouraged to start exploring a new generation of CTBT laboratory techniques. In order for countries to make full use of this data and implement it in solving national, regional and global issues it is important to assist them in developing their capacities.

The quality and availability of training at the CTBTO consists of e-learning modules in several languages and national and regional training programmes for diplomats, scientists, technicians, young people and women at all levels whether novice, intermediate or advanced. It is internationally recognized and commended. Throughout the scientific sessions, several proposals were made concerning capacity development. Under the theme "CTBT in a Global Context", in particular the part that dealt with "Capacity Building, Education and Public Awareness", 11 oral presentations were delivered and nearly 80 posters were accepted. These included discussions on the educational role of the CTBT in peace processes, how the SDGs mutually reinforce the CTBT's mission and give new impetus to the Treaty, integration of women technicians into the CTBTO, an educational site for the resolution of relevant CTBTO issues, how to encourage the generation of science diplomacy to make the CTBT move forward, promoting the CTBT through capacity building, education and public awareness, raising public awareness of positive uses of nuclear energy, the role of civil society organizations in education and public awareness, and the intrinsic value of CTBTO workshops, training programmes and expert meetings.

Overall, SnT2019 offered a great opportunity for communities and regions to meet, and several topics of great importance to different countries were addressed. The panels conducted in French and Spanish were highly appreciated as an effort to include other official United Nations languages and most importantly to overcome barriers.

Valuable contributions were made to further improve and enhance the work currently being done.

This conference was in my opinion a very successful one. I congratulate all of those involved in achieving this result.

Thank you.

5.5. Paul Granston Richards (United States of America), Special Research Scientist and Professor Emeritus of Natural Sciences Lamont-Doherty Earth Observatory, Columbia University

Paul Granston Richards, Professor Emeritus of Natural Sciences Lamont-Doherty Earth Observatory, Columbia University.

Your Excellencies,
Ladies and Gentlemen,
Fellow Scientists,

I was asked to summarize the principal technical results emerging from this five day conference, and in doing this type of summary let us never forget our principal goals for the CTBT: Science and Technology 2019 conference.

We must support ongoing efforts to monitor nuclear explosions.

We must work to improve those efforts with better data and better methods of analysis and by increasing the number of people who understand our technical work by doing it well and by building confidence that we are doing it well.

Achievement of these principal goals is clearly demonstrated by the numerous presentations, done independently in different countries, on the only nuclear test explosion since our last CTBT: Science and Technology meeting in 2017. Many countries with independent data sets and technologies using different methods have achieved what I would regard as a common understanding of the nuclear test of September 2017.

Of course, there is continuous interest in yield estimates for this event. A senior English scientist once wrote that there is no creature on Earth more deserving of pity than the seismologist asked to explain magnitude–yield relationships. At this meeting, we find at an even more basic level that the community is having difficulty with allocating an appropriate seismic magnitude for this last big explosion. There were papers at this conference that I believe can appropriately address this problem, and I think the International Monitoring System and the International Data Centre have potentially a useful role to play here.

Concerning who is the person most deserving of pity, that would be the person asked to summarize in 10 minutes the work of more than a thousand people at a 5 day conference: That would be me.

What then are some other key results from the various themes around which our technical work has been organized at SnT2019?

We are seeing a good level of commitment to preserve the historical data from past explosions, remembering that there were more than 2000 nuclear test explosions — from the first one in July 1945 and then on through the 1950s and 60s and 70s with signals recorded on technologies not used today. I believe it is important to preserve the signals from those tests in the atmosphere, underwater and underground. We had presentations at this meeting that made the point that these old data can be made usable by future generations long after all of us in this room are gone. Another goal of this conference is wider applications of IMS data and IDC products beyond nuclear explosion monitoring. If we contribute in this way, for example by improving our understanding of climate change or by helping monitoring for tsunamis, we must be careful not to forget our primary mission, which is to support a key initiative in nuclear arms control. Yes, we can help with the evaluation of tsunamis, after certain types of earthquake. Perhaps even more important is the potential for monitoring volcanic activity that can threaten civil and military aviation.

I have a long list of other good presentations made at this meeting. It includes, of course, the success of NET-VISA, which provides a whole new way of interpreting the streams of data received in Vienna (which, our Executive Secretary reminded us, now amounts to about 14 terabytes per year). NET-VISA's 10 year development activity has now moved into an operational framework and it is terrific.

I believe that these SnT meetings are being followed up by a final technical report. We were given a flash drive with the report on the last SnT conference. It is very useful to look back and see the progress we have made here.

We heard enthusiastic accounts of crowd sourcing and what it can accomplish. I was glad to hear it, but we must not exaggerate.

In closing, I do want to mention what for me was one of the highlights of the conference, a non-technical presentation on the first day. I was sitting over there, on the side, when a woman next to me stood up and went up on the stage to give us a very moving sand painting. That was Irina Titova, and I thought her performance was outstanding. She really captured the big picture.

Thank you.

Winners of the SnT2019 Global Art Campaign

CATEGORY 1 **Drawings** for students aged 5 to 7	CATEGORY 2 **Posters** for students aged 8 to 12	CATEGORY 3 **Murals** for students aged 13 to 17
1st Anisa Mohammadbagherzadeh Age 7 From Iran	**1st Plamena Krasimirova Krasteva** Age 11 From Bulgaria	**1st Ermina Kalogirou** Age 16 From Cyprus
2nd Zhasmin Kenesbai Age 7 From Kazakhstan	**2nd Aylin Najafi** Age 11 From Iran	**2nd Tara Božović, Milojka Simićević, Mlađen Simićević** Age 17, Age 17, Age 16 From Montenegro
3er Alvaro Cobos Palacino Age 6 From Spain	**3er Petya Dimitrova** Age 8 From Bulgaria	**3er Jasmina Nožić, Edita Ždrale, Lajla Kudović, Danis Bakoš, Adna Ćosić, Rizah Mustafić, Melika Džajić Nejra Boloban, Enisa Nuhić** From Bosnia and Herzegovina
4th Leung Hon Yin Age 4 From China	**4th Mahmoud Mostafa Negm** Age 10 From Egypt	**4th Jana Swanepoel** Age 16 From Namibia

6. Relevance to CTBTO Activities and Verification Science

6.1. Distribution of Presentations among Subject Headings

This chapter reviews the conference highlights and discusses potential focus areas with relevance to future CTBTO activities and verification science.

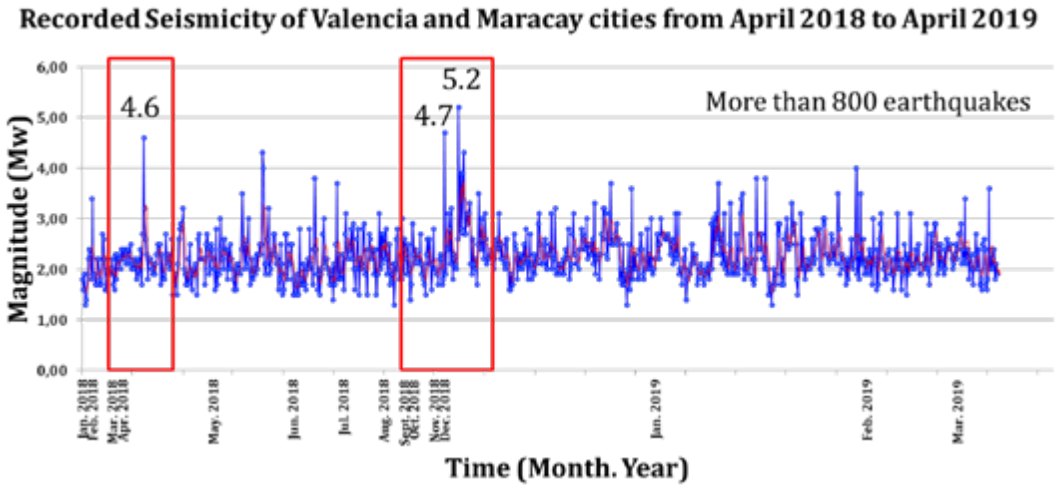


Figure 37. Statistics on the number of posters and oral presentations by topics.

The substructure of this chapter closely follows the main structure of the SnT2017 report by following the logic of the data flow: from data acquisition through data transmission, data processing and analysis, to interpretation. Additional sections cover properties of the earth that are necessary to support verification science, performance monitoring, capacity building and training, as well as policy and advocacy to reflect the introduction of these aspects into the programme. 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 as appropriate. In order to guide the reader in identifying which topic is considered under which sub-chapter, the relevant topics are listed right below the sub-chapter heading. Each topic is assigned to at least one sub-chapter and if a specific topic appears in more than one sub-chapter, the content is not repeated but placed under the appropriate heading.

A scheme for categorizing SnT presentations according to their relationship with CTBTO verification needs was introduced in the SnT2017 report. This scheme identifies four types of relationship, each suggesting a different type of follow-up activity under the SnT process. Under this scheme a presentation may be assigned to one of four categories, according to whether the presentation reports work that is:

- Highly relevant and has CTBTO active involvement (Category 1);
- Highly relevant and is ready for adoption by CTBTO (Category 2);
- Highly relevant, with CTBTO taking an active interest (Category 3);
- Potentially highly relevant, with CTBTO continuing to observe (Category 4).

[6] T1.1. Atmospheric Dynamics, T1.2. Solid Earth Structure, T1.3. Properties of the Ocean, T1.4. Interaction Among the Earth's Subsystems, T2.1. Characterization of Treaty-Relevant Events, T2.2. Challenges of On-Site Inspection, T2.3. Seismoacoustic Sources in Theory and Practice, T2.4. Atmospheric and Subsurface Radionuclide Background and Dispersion, T2.5. Historical Data from Nuclear Test Monitoring, T3.1. Design of Sensor Systems and Advanced Sensor Technologies, T3.2. Laboratories Including Mobile and Field Based Facilities, T3.3. Remote Sensing, Satellite Imagery and Data Acquisition Platforms, T3.4. Augmented Reality and Fusion of Data from Different Monitoring Technologies, T3.5. Data Analysis Algorithms, Artificial Intelligence, Big Data and Deep Learning, T4.1. Network Optimization, T4.2. Systems Engineering, T4.3. Enabling Technologies, T4.4. Performance of the Full Verification System, T5.1. Science in Policy Discussions and Lessons Learned from Other Arms Control Agreements and Arrangements, T5.2. Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and SDGs, T5.3. Capacity Building, Education and Public Awareness

Presentations made at SnT2019 have not been assigned to these categories. However, most highlights presented in this chapter fit into Category 1 or Category 3. Category 2 would also be covered here in some cases.

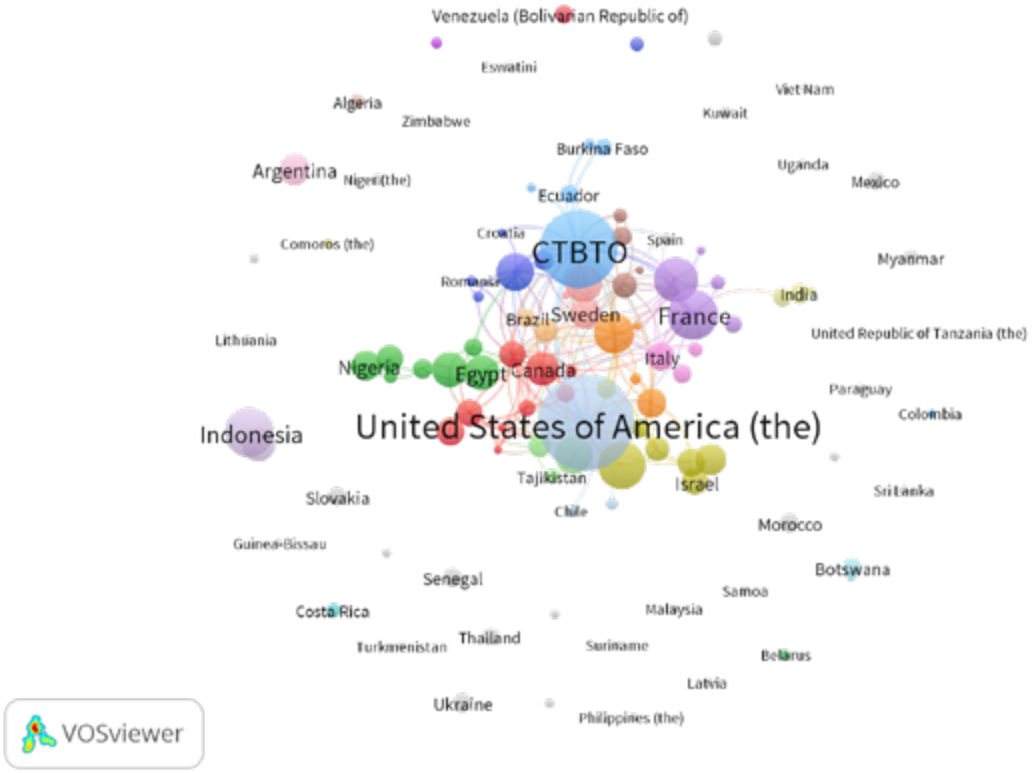


Figure 38. Network Visualization by Country based on the Book of Abstracts (699 abstracts, 56 clusters, 108 countries; CTBTO, IAEA and World Bank were represented indepenently). CTBTO Library developed this figure using Mendeley and VOSviewer Software.

Some presentations made at SnT2019 report work that is not within the scope of the CTBTO but may nevertheless be relevant to the role of States Signatories in their CTBT verification activities. Examples include work on verification technologies not included in the Treaty, magnitude yield relations for underground nuclear tests, or nuclear security. Whatever highlight is reported here has been selected to provide general guidance on the level of relevance of projects to CTBTO activities. Any reference to a specific presentation is a scientific judgment made in the light of verification needs and has been made by individual specialists without any formal review process. Highlighting specific research and development activities in this report is unrelated to any prospect of financial support, contractual arrangement, contribution in kind or other relationship between the CTBTO and the authors of the presentations or their institutions. Neither does it imply that specific actions will necessarily be taken by the CTBTO in regard to the subject presented.

[7] The size of the bubble is corresponds to how many authors listed in the abstracts affiliated their countries in the Book of Abstracts of SnT2019. The clusters are represented by colours (more details in Appendix 7). They are related to the countries in co-authorship. The bubbles in grey are those who presented abstracts as a sole authorship. Lines between bubbles represent connections between countries. The distance between two bubbles indicates the relatedness of both in terms of frequency. The closer two countries are located to each other, the stronger their relatedness.

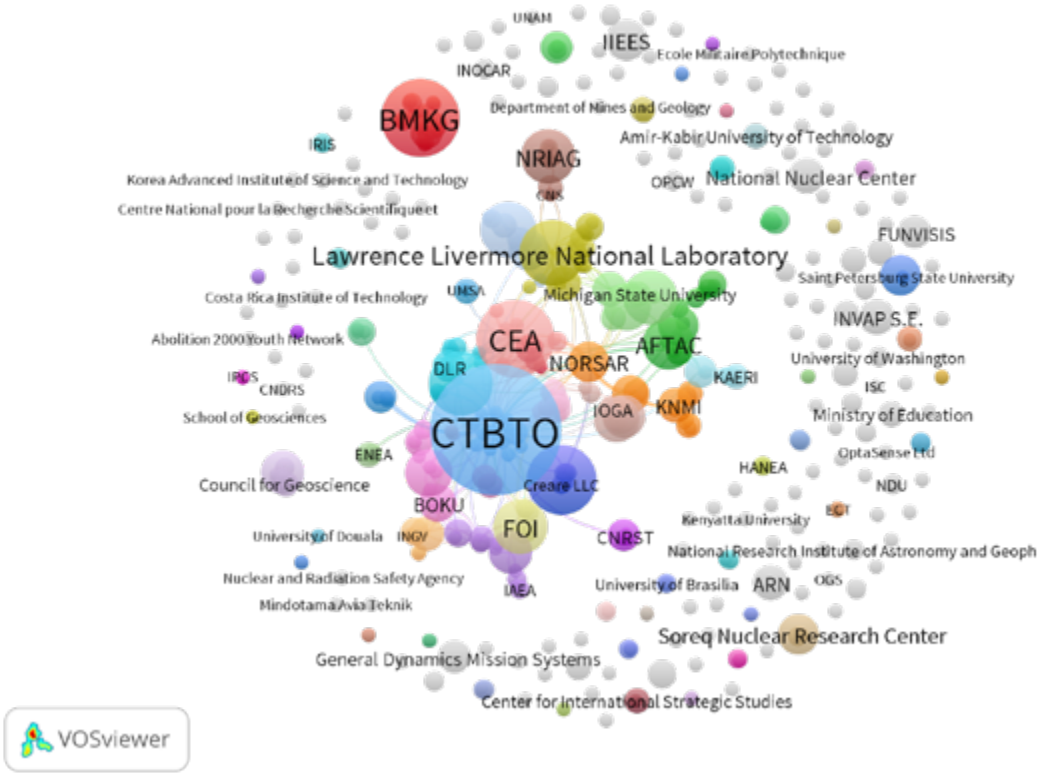


Figure 39. Network Visualization by Institutions based on the Book of Abstracts (699 abstracts, 453 institutions, 212 clusters). CTBTO Library developed this figure using Mendeley and VOSviewer Software. Completed list of institutions is available in Appendix 7.

6.2. Data Acquisition

Relevant Topics
T2.2: Challenges of On-Site Inspection
T3.1: Design of Sensor Systems and Advanced Sensor Technologies
T3.2: Laboratories Including Mobile and Field Based Facilities
T3.3: Remote Sensing, Satellite Imagery and Data Acquisition Platforms

Sensors and Measurements

The development of noble gas monitoring technology for the CTBT verification regime aimed at increased performance, improved collection properties and reliability. Research projects have been identifying and characterizing new sorption materials such as metal-organic frameworks, zeolite, activated charcoal and new absorbing mediums (**T3.1-04**, **T3.1-P18**, **T3.1-P32**, **T3.1-P38**).

New detectors and processes have improved performance in terms of sensitivity or nuclide separation (**T3.1-05**, **T3.1-P3, T3.1-P25)**.

[8] The size of the bubble is according on how many authors listed in the abstracts affiliated their institutions in the Book of Abstracts of SnT2019. The clusters are represented by colours (more details in Appendix 7). They are related to institutions in co-authorship. The bubbles in grey are those who presented abstracts as a sole authorship. Lines between bubbles represent connections between institutions. The distance between two bubbles indicates the relatedness of both in terms of frequency. The closer two institutions are located to each other, the stronger their relatedness.

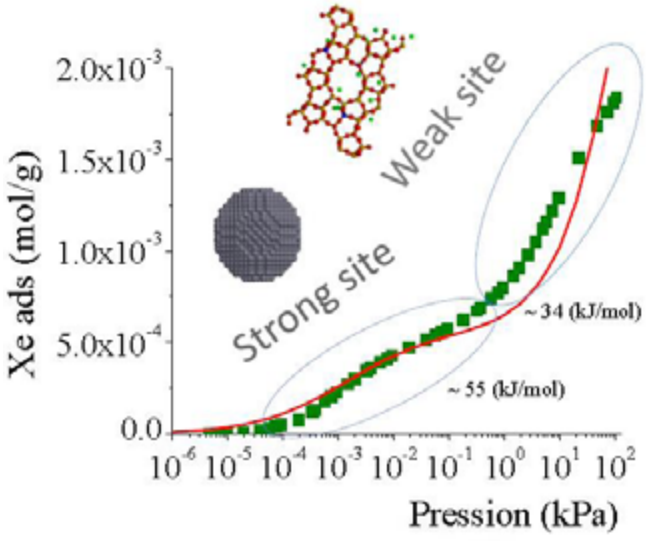


Figure 40. Silver nanoparticles doped zeolite capture Xe more than one order of magnitude greater than typical active carbons. From A. Monpezat et al. (T3.1-P3).

Several next-generation xenon measurement systems are close to deployment and undergoing calibration, validation and acceptance testing (SAUNA III, SAUNA CUBE, SPALAX NG) or are close to starting this process (MIKS, Xenon International) (**T2.2-P8**, **T3.1-P15**, **T3.1-P32**, **T3.1-P33**, **T3.1-P34**, **T3.1-P35**, **T3.1-P41**).

Significant efforts were made by the metrology community to better characterize infrasound sensor performance in laboratory and operational conditions (**T3.1-P9, T3.1-P10, T3.1-P48)**. In addition, the use of feedback loops within infrasound sensors could further increase sensor passband and ease the adjustment of sensor sensitivity (**T3.1-01).**

New studies on the use of existing surface and underwater telecommunications fibre optic cables for the detection of seismic waves by detecting changes to backscattered light promise interesting civil and scientific applications. Some of these systems appear to have the capability to resolve the seismic low noise model in some parts of the passband monitored for Treaty verification (**T3.1-010**).

Monitoring Facilities

Higher-sensitivity analysis of CTBT-relevant radionuclides at IMS radionuclide laboratories can support special studies by reducing the background using the gamma–gamma coincidence technique in addition to cosmic veto shields and low background material (**T3.2-02**). The enhancement of noble gas measurement capability at IMS laboratories by increasing sample throughput with additional detectors and the use of a beta–gamma coincidence system was also presented (**T3.2-03, T3.2-P2**).

Several studies have investigated whether antineutrinos that are emitted from a nuclear explosion could be detected at distance. In principle, the detection of antineutrinos could be used as proof that a nuclear explosion has occurred. In practice, however, the size of an antineutrino detector required to reliably detect a nuclear test poses a practical limitation. The findings overall indicated that global monitoring is not possible, as the size and cost of the detectors would be too large. Site monitoring would be feasible in principle, but the cost would be prohibitive compared with other monitoring technologies (**T3.1-03**, **T3.1-08**, **T3.1-P5**).

Strategies for On-Site Inspection

The use of more advanced and accurate gravity sensors based on quantum technology in an OSI context, to improve the detection of subsurface features of OSI relevance, such as tunnels and blast chambers, was presented (**T3.1-07**).

The inclusion of directional sensing and unmanned aerial vehicles in gamma spectroscopy surveys can provide enhanced capabilities for OSI (**T3.1-P47**). A ruggedized gamma–gamma based system for in-field measurement of environmental samples that can measure 17 OSI-relevant radionuclides and weed out other radionuclides that might be present in a sample can be applied when measurement restrictions are required. A silicon photomultiplier-based Compton telescope gamma imager and survey spectrometer that performs a sort of triangulation to characterize the distribution of radioactivity has been developed to reconstruct an extended source located in a restricted access site in support of inspection activities during an OSI (**T2.2-05**).

A newly developed SAUNA-FIELD system with simplified deployment and an improved automation process for the measurement of sub-soil noble gas xenon samples during an OSI reduces an inspector's workload and increases measurement capacity (**T3.2-P5**). For OSI, measurement of ^{37}Ar is of particular interest. Some high throughput argon measurement systems based on liquid scintillation technology have been developed and tested (**T3.1-06**, **T3.2-01**).

Interferometric instrumentation mounted on drones at relatively low elevation, which enables a very dense cloud of observations leading to high spatial resolution, would be a valuable addition to OSI visual observation (T2.2-08).

A newly developed airborne simulator for visual observation, multispectral, gamma and magnetic surveys to support the training of surrogate inspectors and testing of OSI equipment in realistic settings was presented (T3.3-P7). Optimization of multispectral including infrared imaging for OSI within the limited space of an aircraft was examined (T3.3-P10).

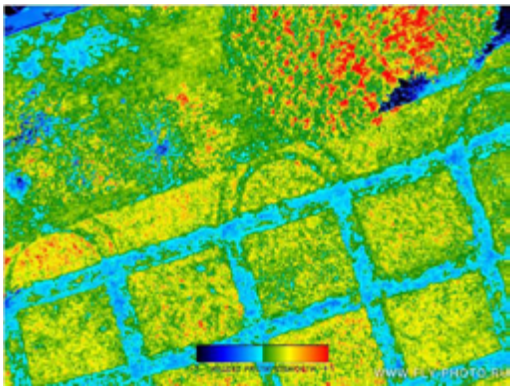


Figure 41. Multispectral mapping showing abnormal areas during an OSI field exercise. From I. Markov and D. Sagaradze. (T3.3-P10).

The availability and utilization of unmanned systems for environmental sampling in harsh and or hazardous environments, such as those contaminated with high or lethal levels of radioactivity, could play a valuable part in an OSI (**T2.2-09**).

Use of the in situ uniaxial compressive strength test technique, which is a non-destructive test for rapid assessment of the condition of rocks, would help enable rapid determination of the nature and characteristics of in situ rocks and support the application of other OSI techniques (**T2.2-01**).

6.3. Data Transmission, Storage and Format

Relevant Topics
T3.1: Design of Sensor Systems and Advanced Sensor Technologies
T3.2: Laboratories Including Mobile and Field Based Facilities
T3.3: Remote Sensing, Satellite Imagery and Data Acquisition Platforms

Standard station interface (SSI) software is data acquisition software that has been specifically developed to acquire, format, sign, buffer and transmit IMS waveform data using IDC formats and protocols. It has been under development by the PTS since 2001, and it is deployed at more than 150 IMS seismoacoustic stations (**T3.3-P8**).

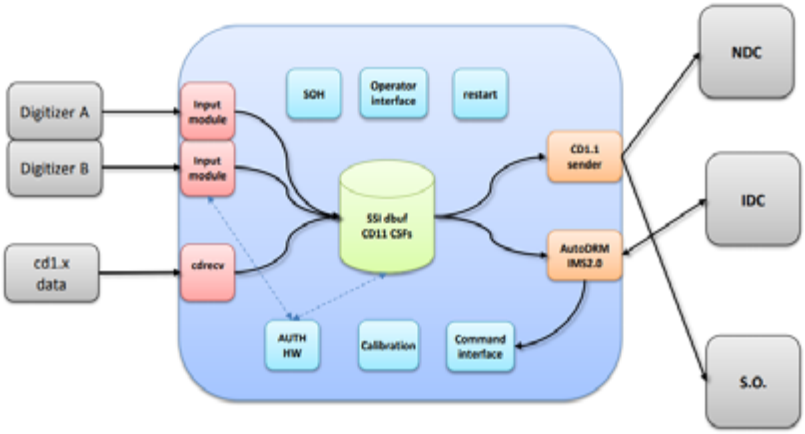


Figure 42. Schematic of the CTBTO Standard Station Interface data acquisition software system composed of individual control modules. The latest PTS development of the software focuses on the command and control, calibration and State of Health monitor. From V. Miljanovic et al. (T3.3-P8).

It is available to all authorized users of IMS data and IDC products and allows reliable transmission of standardized Continuous Data (CD-1.1) to the IDC in Vienna. The latest development of the software also includes modules for command and control, calibration and state of health monitoring. The PTS continuously receives new requests from station operators for new features, including interfacing with new types of equipment and additional station monitoring capabilities. The use of SSI software by National Data Centres and equipment manufacturers, for example in Linux embedded digitizers, is increasing. For this reason, it is very important for the PTS to continue working on this topic with the CTBTO and scientific communities and to report on a regular basis to these communities at workshops and conferences.

6.4. Data Processing and Synthesis

Relevant Topics
T2.1: Characterization of Treaty-Relevant Events
T3.2: Laboratories Including Mobile and Field Based Facilities
T3.4: Augmented Reality and Fusion of Data from Different Monitoring Technologies
T3.5: Data Analysis Algorithms, Artificial Intelligence, Big Data and Deep Learning

Processing of Seismic, Hydroacoustic and Infrasound Data

It is well known that methods of event detection and location based on WCC improve the accuracy of relative location by two orders of magnitude, including for events with smaller magnitude than those in the Reviewed Event Bulletin (**T3.5-04**, **T3.5-05**, **T3.5-P19**). The number of seismic events may grow by an order of magnitude with the detection techniques using WCC, making this technique more suitable for full automation or specialized usage such as spot-checking automatic or analysed events.

Large aftershock sequences present a challenge for analysis. Promising methods, including WCC-based methods, were presented to mitigate this issue (**T3.5-09**, **T3.5-P11**, **T3.5-P14**).

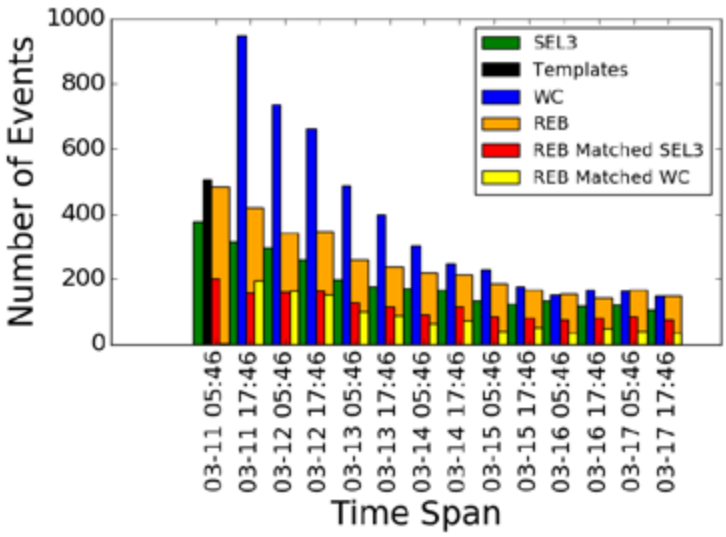


Figure 43. The graph demonstrates the potential utility of waveform correlation for aftershock processing by showing the number of events detected by two or more stations in 12-hour time periods after the mainshock during the 2011 Tohoku, Japan, aftershock sequence. Waveform correlation (WC) (blue bars) versus SEL3 (green) and REB (orange) events, REB events that matched SEL3 (red) and waveform correlation (yellow) events within the tolerances of 1.0° in distance and ±15 seconds in time. From A. Sundermier et al. (T3.5-P11).

A number of IMS arrays have been upgraded and now use three-component seismometers at all their sites. The current processing uses only the vertical component of three-component seismic arrays. It would make sense to also use the horizontal components for automatic S-phase detection, classification and identification (**T3.5-P35**).

Machine learning techniques ranging from Bayesian inference to convolutional neural networks have the potential to exploit the large amount of data archived at the IDC and improve both automatic and analysed results. Some of these techniques have become operational, including NET-VISA (**T3.5-010**, **T3.5-014**), which is now successfully used for event building based on detections. Bayesian methods allow for complex physical models to be included in the generative model, which makes them suitable to include advances in complex physical modelling, for instance travel times from 3-D velocity models. Another example would be to include locality-dependent knowledge about seismic wave attenuation.

Efforts are being made to tune the neural network parameters for three-component seismic stations phase identification, while investigations also show the benefit of aiming for more advanced classifiers, such as convolutional neural networks (**T3.5-P12**).

Diffusion maps are being applied to the detection of repeating events (**T3.5-07**), gradient-boosted regressors to the rapid emulation of 3-D travel times (**T3.5-09**), and convolutional neural networks to the detection and location of earthquakes (**T3.5-P16**, **T3.5-P22**).

Improvements to CTBT monitoring include more than IMS instrumentation improvements and IDC software improvements. New seismic networks contribute to the understanding of the seismicity background and seismic propagation characteristics (**T3.5-012**).

Multi-Technologies Processing

There is strong interest in fusing data of different types, not only using waveform data (**T3.4-P2**), which comes naturally with the IMS, but also combining non-IMS technologies with IMS technologies (**T2.1-06**, **T3.3-P5**).

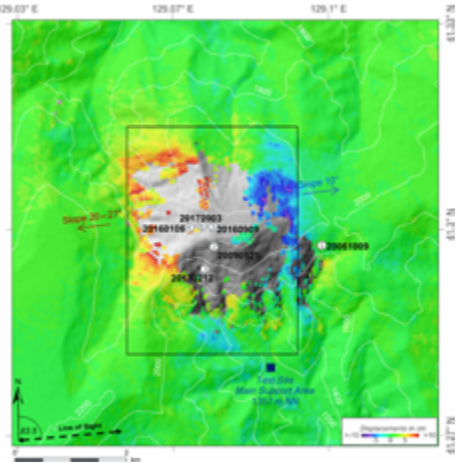


Figure 44. Results of remote sensing analysis of the 2017 North Korean nuclear test using DInSAR with ALOS-2 satellite data from 29 August and 12 September 2017 show subsidence of up to 10 cm in the eastern part of the Mount Mant'ap massif and uplift of up to 10 cm in the western part of the Mount Mant'ap massif. From P.J. Gaebler et al. (T2.1-06). More details in: P. Gaebler et al, A multi-technology analysis of the 2017 North Korean nuclear test, Solid Earth, 10, 59–78, (2019). DOI: https://doi.org/10.5194/se-10-59-2019.

T3.4-01 presented augmented reality work that may be of potential interest for OSI, where inspectors would be able to access satellite imagery and elevation data from the inspected State Party and open sources as well as IDC products in a virtual environment while working in the field.

Radionuclide Processing

Several presentations (**T3.5-P37, T3.5-015**) described the complete re-engineering of the IDC radionuclide application software with unified software for automatic processing of radionuclide spectra from all IMS radionuclide stations (including particulate stations and noble gas systems) as well as an integrated platform for interactive review of all radionuclide data.

An objective Bayesian computation framework was presented (**T3.5-P58**) to create a model of radioxenon background concentrations that minimizes the difference between the measurements and model predictions by altering a few parameters. The results of the calculation can be interrogated to obtain most probable values for source magnitude, release time and release location.

The overall message from the session might be that the CTBT: Science and Technology community is encouraged to start exploring the next generation of CTBT laboratory techniques. Technological innovations in noble gas measurement equipment include liquid scintillation to analyse ^{37}Ar for OSI applications (**T3.2-01**), a gamma–gamma coincidence technique to lower the detection threshold (**T3.2-02**) and using four additional noble gas detectors to improve energy resolution (**T3.2-03**).

6.5. Earth Characterization

Relevant Topics
T1.1: Atmospheric Dynamics
T1.2: Solid Earth Structure
T1.3: Properties of the Ocean
T1.4: Interaction Among the Earth's Subsystems

The understanding of the atmosphere remains a challenge when considering nuclear verification, building and maintaining support for the CTBT and civil and scientific applications. A topic widely covered to characterize the atmosphere was the improved knowledge of the atmospheric variability and the uncertainties associated with it (**T1.1-01**, **T1.1-011**). A wide array of research groups within the infrasound and atmospheric transport modelling communities are undertaking this challenging question. The need to more accurately estimate an event energy release, thus helping to characterize the event source, was highlighted (**T1.4-01**) and the usefulness of dense seismic networks when studying the complex propagation of infrasounds generated by explosions was discussed (**T1.4-02**).

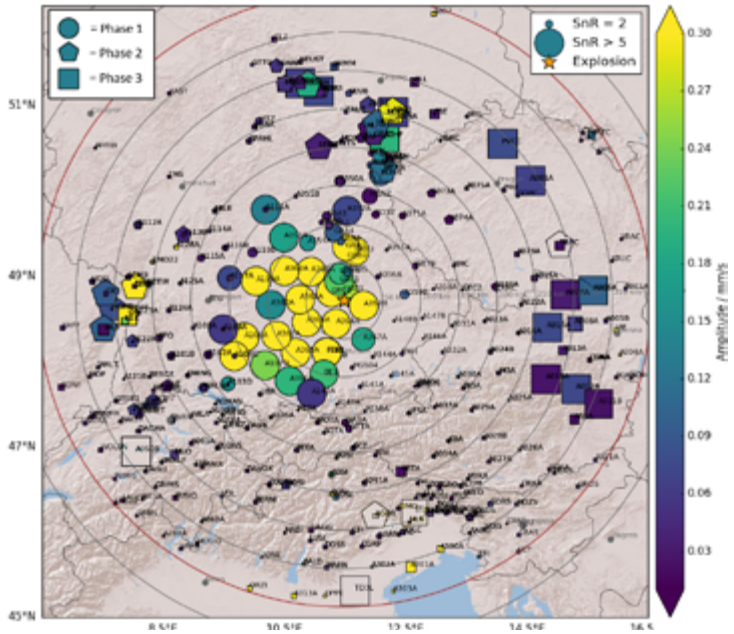


Figure 45. Complex propagation for the Ingolstadt (Germany) explosion that generated infrasound revealed by the large-scale AlpArray seismic network. Illustration of the spatial distribution of seismoacoustic detections with phase type and amplitude levels recorded. From F. Fuchs et al. (T1.4-02).

Enhancing the understanding of the atmosphere is beneficial for the CTBTO because it leads to improved detection, association and location results of IMS data and IDC products and for expert analysis. It is also a crucial prerequisite for advancing numerical weather forecasting models (**Highlight Talk 1**) and refining their accuracy. In this process, the understanding of physical processes in the atmosphere from the ground to the thermosphere is key alongside the multiyear recordings of IMS data now available, which allow atmospheric trends to be extracted (**T1.1-02**).

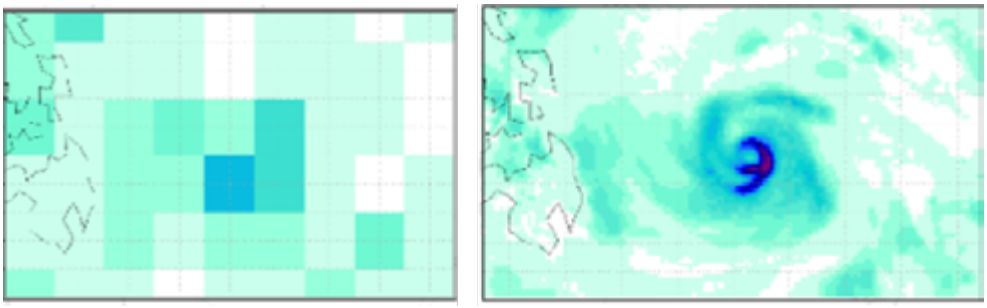


Figure 46. Improved numerical weather predictions demonstration from World Weather Research Programme with the example of total precipitation of Typhoon Halyan (2013): from 1981, global model with 200 km resolution (left) to 2016 global model with 12 km resolution (right). From Highlight Talk 1: M. Jean. Structure and Dynamics of the Atmosphere.

Whether one considers monitoring of the solid earth, the atmosphere or the oceans, it is clear that a large amount of information already exists, with new data being added on a daily basis. The processing of this data aimed at enhanced modelling possibilities and analysis techniques will require substantially different approaches than the current norm (**Highlight Talk 1**).

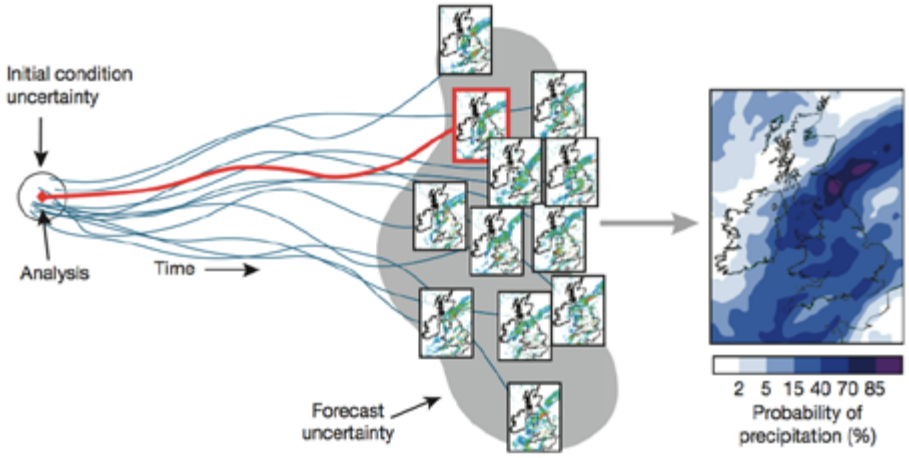


Figure 47. The Ensemble Prediction Paradigm allowed to improve numerical weather predictions and it brings open questions for further improvements, delivery of tailored products, communication of warnings and alerts and how to best use technology. Illustration from Peter Bauer et al. The quiet revolution of numerical weather prediction (Nature, 2015). From Highlight Talk 1: M. Jean. Structure and Dynamics of the Atmosphere.

The need for accelerated development of artificial intelligence to deal with this data is already part of an intense discussion at different fora, including in the CTBTO. A particular challenge that has already been recognized is to identify where the data are being held. In addition, the type of available data is important for decisions on the application of data. While the CTBTO has to concentrate on data for the purposes of nuclear verification, it is also important to acknowledge that the availability of IMS data and IDC products plays an essential role in building and maintaining support for the CTBT. It is expected that this trend will grow in the future and will also encompass global data processing and forecasting systems. A good example of this would be the benefits that can be extracted from IMS infrasound and hydroacoustic data for numerical weather prediction centres to build enhanced models that will lead to more accurate analyses and forecasts (**Highlight Talk 1**).

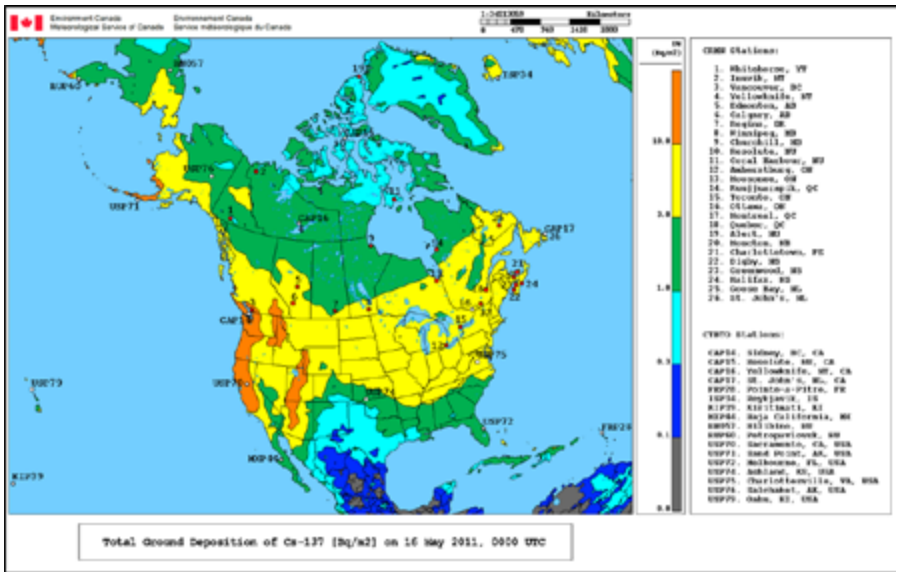


Figure 48. Estimation of 137Cs ground deposition over North America after the Fukushima nuclear accident. Estimates of radioactive material from Fukushima were corroborated by IMS station data. From Highlight Talk 1. M. Jean. Structure and Dynamics of the Atmosphere.

Regardless of the type of data, the real value lies in combining it (**T1.1-06**).There is currently no other system like the CTBT verification system, which can acquire, analyse and use data. More scientists should be made aware of the existence of IMS data and be given access to it, as continuous use of CTBTO data and different approaches to the analysis of it will unlock future benefits at a higher rate. Waveform data is known to be complex, and the deeper we mine into such data, the more useful information can be identified. It can be used to distinguish between different seismic sources, but there are hidden intricacies that may take more time and resources to come to a final conclusion.

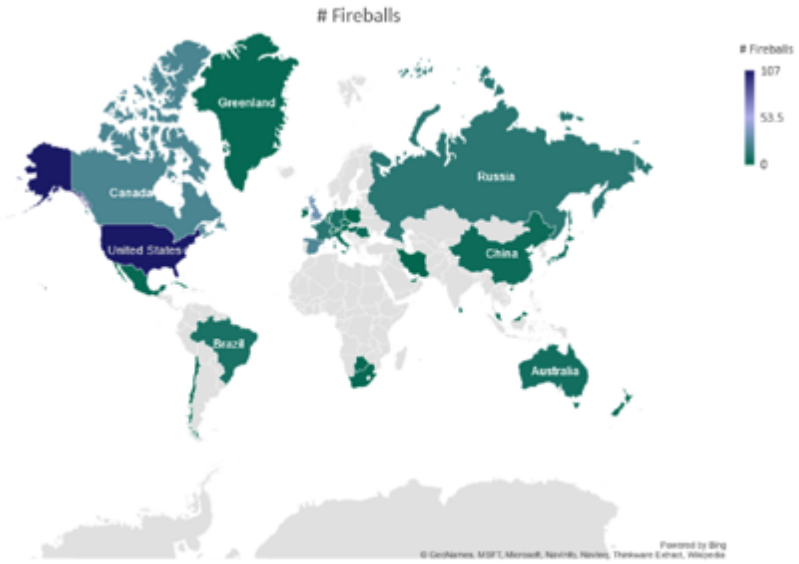


Figure 49. Mapping over 300 fireball events reported by NEMO (Near real-time MOnitoring system) for the period August 2017 to March 2019, From T.L.M. Ott et al. (T1.1-06).

The ability to locate the source of an event with a high degree of accuracy is also a very important component of being able to differentiate between natural and man-made sources. In the solid earth environment, the seismic velocity model is one of the factors that influence the accurate location of events the most. Although the IMS is a global monitoring network, the ability to locate events accurately in any region of the world depends on the availability of high resolution velocity models for all regions. Local tomographic studies and ground truth events may enhance location accuracies in the future for many regions in the world (**T1.2-01**).

An ongoing area of development and significant advances since 2014 is the regional seismic travel time (RSTT) tomographic model. The approach is used to compute the model on the paths joining the events with the stations recording the events. The model is using a large number of well-located seismic events and has been developed to improve travel time predictions for regional phases (Pn, Sn, Pg and Lg). The goal is to increase seismic location accuracy, with a special focus on explosive sources. It is specifically developed to exploit regional phases in combination with teleseismic arrivals for location purposes (**T1.2-06**).

Technical meetings on RSTT had an initial focus on the Latin America and the Caribbean region. After a successful rollout, the meetings moved to the African continent, and more recently the focus has shifted to Asia. These are regions where gaps in coverage from early versions of the RSTT software were identified.

Regardless of the software tools being used, as more and more permanent and temporary stations are deployed, covering large areas of the globe and detailing the seismicity of many regions, additional information on seismotectonics and crustal structures will become available. The combination of this information with 3-D tomographic modelling provides extensive opportunities to develop holistic velocity structures that can contribute to more accurate location assessment of any event, anywhere on the globe and with a realistic reflection of the uncertainty associated with the solution.

The value of the IMS hydroacoustic network for detecting small impulsive sources was reaffirmed with the analysis of IMS data relating to the tragic loss of the Argentine submarine *ARA San Juan*. Three independent analyses came to effectively the same conclusion **(T1.3-01**, **T1.3-03**, **T1.3-09)**.

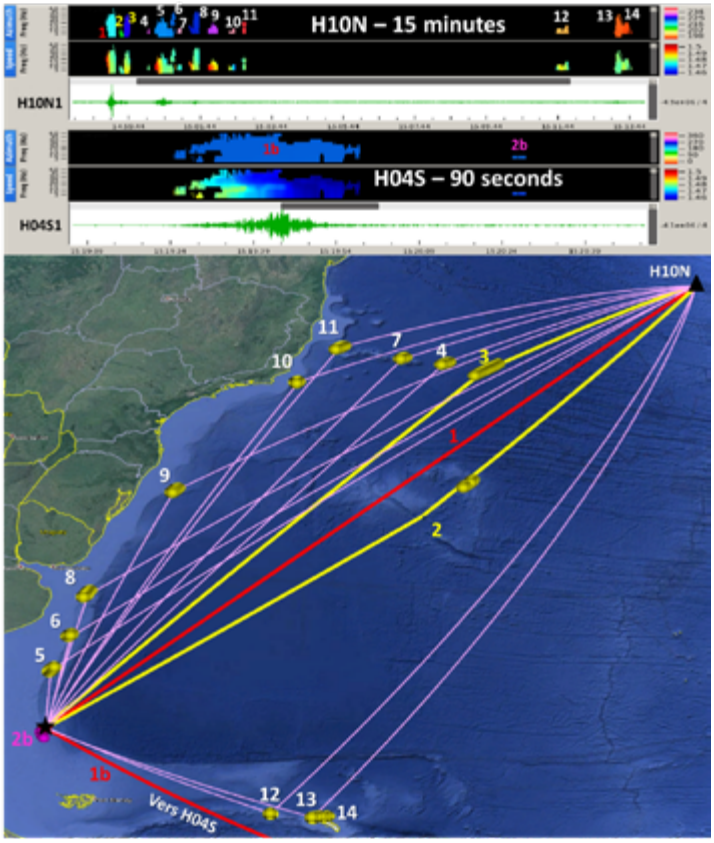


Figure 50. Estimate of location (stars) and associated uncertainty (error ellipses) of the unusual impulsive-like signal recorded on the CTBT IMS triplets H10N and H4S on 15 November 2017. The event location was found to be less than 20 km from the reported location in which the Argentine submarine ARA San Juan was found the night between 16 and 17 November 2018. The red error ellipse was determined by using only the two hydrophone stations (H10N and H4S) in the event location. The small green and pink error ellipses were determined by incorporating data from one or two non-IMS seismic stations that detected the same event. Although these seismic stations had little impact on the actual event location estimate, their data combined with the hydroacoustic data from the IMS stations resulted in a reduction of the location error ellipse by a factor of 50. From J. Vergoz et al. (T1.3-01).

Detailed analysis of this particular event provided an increased understanding of hydroacoustic signal propagation in the oceans. Clear evidence of reflected propagation paths from continents and underwater bathymetric features like sea mountains has shown value in event localization accuracy and minimization of location uncertainty by incorporating these multiple propagation paths. Increased resolution and data quality of oceanographic and bathymetric database information, and development of complex underwater acoustic propagation models provide capabilities in identifying multiple propagation path arrivals that can improve event localization (**Highlight Talk 3**).

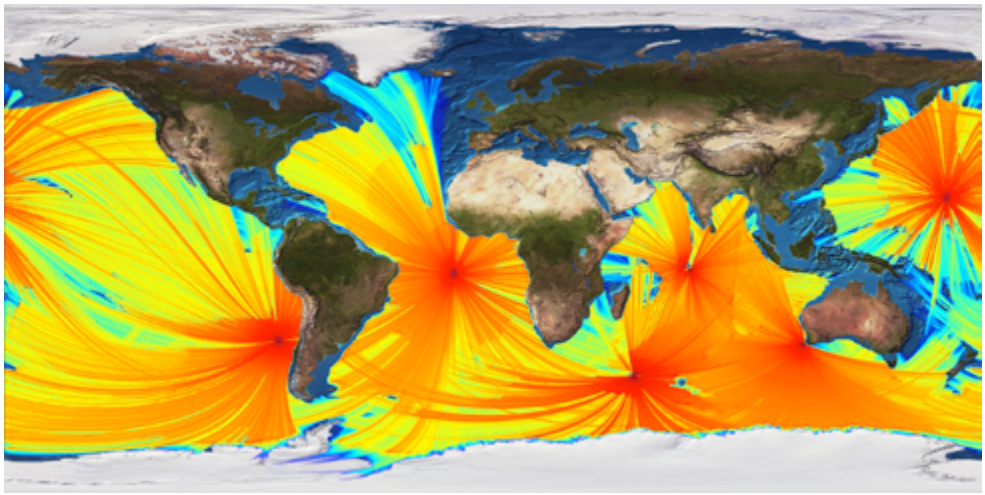


Figure 51. Three dimensional underwater acoustic propagation demonstrating the low-frequency acoustic coverage of the CTBT IMS hydrophone stations. From Highlight Talk 3. H. Sagen. Structure and Dynamics of the Ocean. Figure source: K. Heaney. Advanced computation of three dimensional long range acoustic propagation for improved localization methods. International Hydroacoustic Workshop, CTBTO, Vienna, Austria, June 2015.

The improved contribution of IMS T stations to event detection and localization requires better understanding of the conversion of underwater acoustic pressure waves propagating in the oceans to land based seismic waves recorded at the IMS T stations. Recent development of complex wave propagation modelling tools includes this wave-type conversion in predicting seismic time series at T stations from events in the oceans. This modelling capability supported by IMS and non-IMS data provides insight for subsequent analysis and for possible incorporation into CTBTO IDC processing **(T1.3-02)**.

Generally, presentations in session T1.3 highlighted the key ingredients to successful maritime operations, including robust engineering, understanding the environment, sustainment through modularity and planning using quantitative probabilistic risk reduction. These ingredients were emphasized to ensure effective resource allocation and ensure continued data availability and are in line with the current CTBTO strategy. Hydrophone station modularity that allows additional environmental sensors may enhance long-term ocean monitoring and is paramount for the IMS hydroacoustic network concerning performance monitoring.

The wide range of applications derived from IMS data and IDC products gather a larger interest from the CTBT communities. The uniqueness and recently achieved global coverage of noble gas and infrasound networks offer never seen before opportunities to better characterize the geosphere and its interfaces, and particularly the atmosphere (**T1.1-04**, **T1.1-05**).

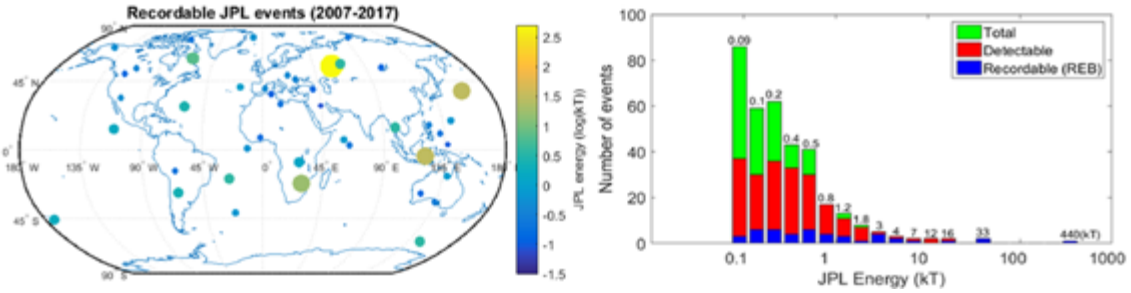


Figure 52. Bolide infrasound and the IMS: Comparison between US government sensors (NASA JPL) fireball data and fireballs recorded by IMS network between 2007 and 2017. From P. Brown and N. Gi. (T1.1-05).

All the components of the earth: namely the solid earth, the atmosphere and the oceans, are already complex when considered individually. However, the level of complexity increases exponentially when studying the interaction among the earth's subsystems. The task is challenging but essential because combining data sets from different technologies has the potential to provide more accurate estimates of important CTBTO parameters (i.e., nature of an event, location in space and time, etc.). The key is to have the required data sets to carry out these studies.

6.6. Interpretation

Relevant Topics
T1.1: Atmospheric Dynamics
T1.2: Solid Earth Structure
T1.3: Properties of the Ocean
T2.1: Characterization of Treaty-Relevant Events
T2.2: Challenges of On-Site Inspection
T2.3: Seismoacoustic Sources in Theory and Practice
T2.4: Atmospheric and Subsurface Radionuclide Background and Dispersion
T2.5: Historical Data from Nuclear Test Monitoring
T3.5: Data Analysis Algorithms, Artificial Intelligence, Big Data and Deep Learning
T5.2: Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals

In the CTBT verification context, interpretation of data relates to the detection, location and characterization of events. This information leads to the identification of nuclear explosions. To distinguish nuclear explosions in the data, it is not only necessary to accurately comprehend the recordings, but also to understand the sources and the propagation effects. Reviewing data from past nuclear explosions also enhances the interpretation of data. At SnT2019, numerous studies focused on the interpretation of observations to identify naturally occurring events, such as earthquakes, volcanic activity or meteorites impacting the atmosphere, or to distinguish between naturally occurring radioactivity and radioactivity of anthropogenic origin, such as chemical explosions or the production of medical isotopes. Analyses of geophysical and radionuclide signatures are crucial for the identification of nuclear explosions and for the establishment of screening criteria that are applied to events by the IDC. Such criteria are defined in the Protocol to the Treaty and applied with the intent to screen out phenomena that are believed to be consistent with natural or non-nuclear anthropogenic activity.

Geophysical Signatures

For seismic events and as for past SnT conferences, the moment tensor technique proved to be an important approach for distinguishing types of sources. The technique was applied for the nuclear test announced by the Democratic People's Republic of Korea in 2017 and for the subsequent event located in the vicinity of the test site (**T2.1-04**). The technique appears to be reliable for consideration to be implemented by the IDC. The nuclear tests by the Democratic People's Republic of Korea remained a topic of interest within the SnT community. Numerous independent analyses of the announced nuclear test on 3 September 2017 demonstrated common understanding and increased confidence in IMS monitoring capabilities. This event of interest provided the opportunity to test methods and learn lessons, in particular with respect to the estimation of the event depth (**T2.1-05**) and event location and magnitude (**T2.1-06**). Absolute and relative locations of the nuclear tests estimated using the cross-correlation method (**T2.1-P9**) demonstrated the possibility to improve location by two orders of magnitude. To support such developments, valuable progress towards preserving and making available for research digitized data of historic nuclear explosions was presented (**T2.5-01**).

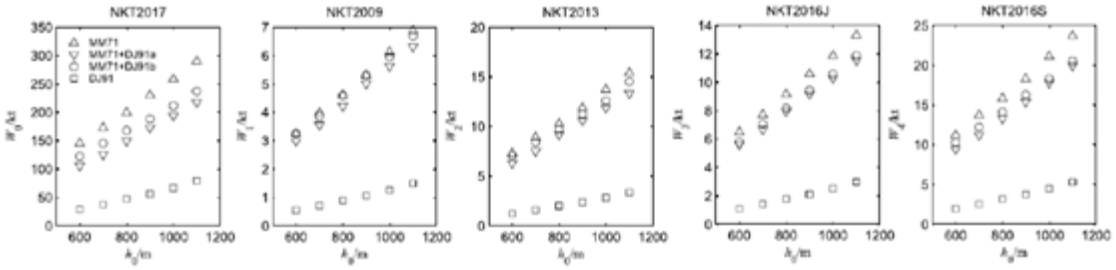


Figure 53. Yield estimations of Democratic People's Republic of Korea nuclear tests depth of burial by different types of source models. From P. Jin. (T2.1-05). More details in: P. Jin et al, Seismic Spectral Ratios between North Korean Nuclear Tests: Implications for their Seismic Sources, Journal of Geophysical Research Solid Earth, (2019). DOI: 10.1029/2018JB016554.

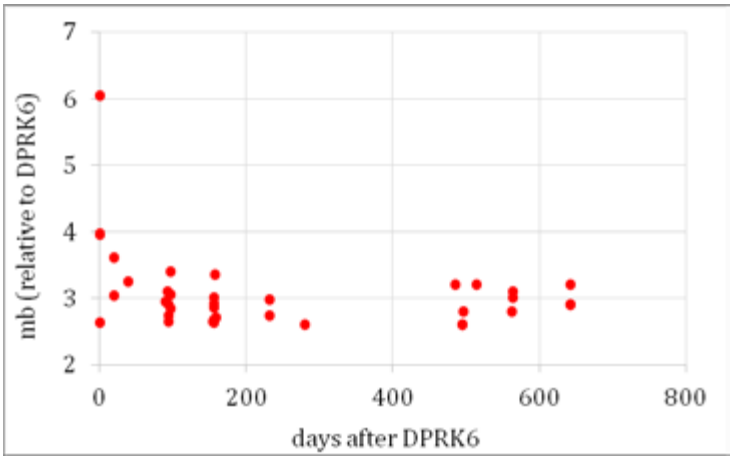


Figure 54. Magnitude of aftershocks (mb) following the 2017 Democratic People's Republic of Korea nuclear test (DPRK6) with magnitude mb 6.0. Aftershock activity lasts for more than 20 months. From I. Kitov and M. Rozhkov. (T2.1-P9).

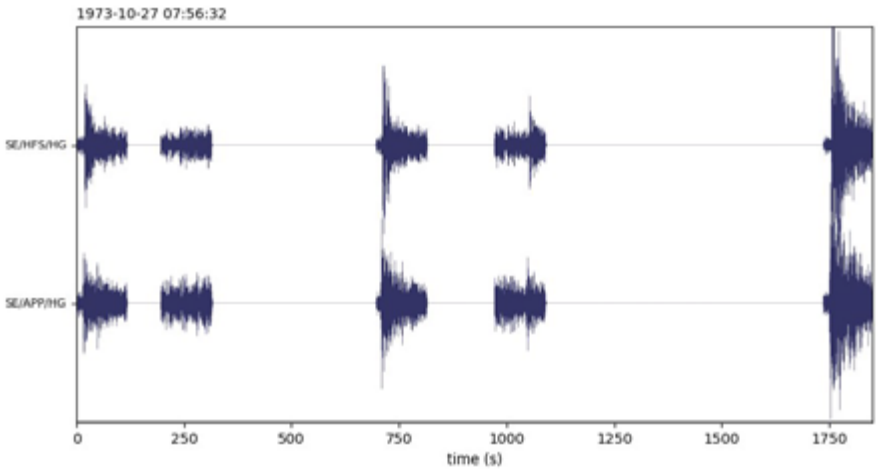


Figure 55. Stitched traces from scans of four aftershocks following the Novaya Zemlya nuclear test on 27 October 1973, recorded by Hagfors (HFS) and Äppelbo (APP) stations. In between aftershocks the plotter was paused and no data is available. From C.F. Hellesen et al. (T2.5-01).

The fusion of technologies, in particular between seismic and infrasound, for the six announced nuclear tests by the Democratic People's Republic of Korea further establish the usefulness of synergies for event characterization (**T2.3-01**). Synergies between IDC techniques and National Technical Means also add to the comprehensiveness of the source mechanism and facilitate interpretation (**T2.1-06**) as well as complement analysis with openly available seismic data to better constrain the source depth (**T2.3-02**). Further to such efforts to discriminate between event types, the source physics experiments at the Nevada National Security Site in the United States of America test explosion scenarios and observation in the near and far field to validate the interpretation.

On the topic of natural sources that can generate strong explosion-like signals, recent meteorite events impacting the atmosphere are widely studied (**T2.1-01, T2.3-P5**). The characterization of such events recorded by infrasound stations proves to be a challenge. However, the high quality of IMS data allows the identification of observations with novel techniques, which leads to revisiting historical data to extract such events and build systems to characterize meteorite events in the future (**T1.1-05**). Similar efforts are carried out for monitoring global volcanic activity with seismoacoustic networks. Both applications highlight the crucial role of the high quality and highly reliable data of the IMS network, which can be complemented with local observation means as demonstrated for volcanic monitoring (**T5.2-05**) and for fireball observation (**T1.1-06**).

For the seismic technology, earthquake detections by IMS stations supported advances in earth sciences on global, regional and local scales with a key benefit resulting in better location accuracy for CTBT monitoring (**T1.2-04**). Waveform correlation processing methods were also demonstrated to be effective for the analysis of aftershock sequences for operational monitoring systems with a sparse global network (**T3.5-P11**).

Recent advances in waveform technology also led to enhanced signal analysis and interpretation. In hydroacoustic technology, the possibility to identify direct and reflected paths on various bathymetric structures and to perform event location was demonstrated (**T1.3-01**). A study of the synergy between atmospheric observation and modelling with infrasound data (**T1.1-011**) highlighted the strong link between improvement in middle atmosphere weather models and accurate infrasound analysis with signal interpretation.

Radionuclide Signatures

The analysis of signals in radionuclide spectra has advanced over many years. There is still room for innovation. Attractive prospects were introduced, such as to assess detection limits for radionuclide monitoring using a Bayesian framework (**T3.5-01**) or to demonstrate the relevance of application of gamma spatial imaging in the context of an OSI (**T2.2-05**).

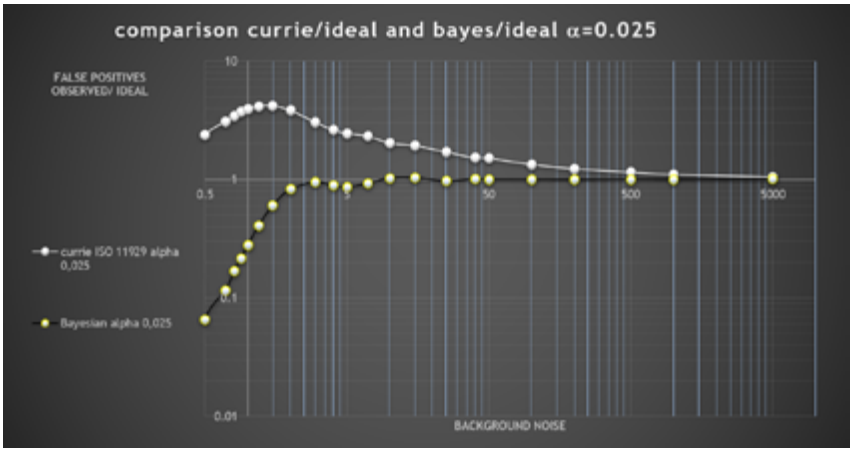


Figure 56. The comparison between Currie ISO 11929 standard and a Bayesian framework offer better decision thresholds using the Bayesian credible interval. From G.A. Manificat. (T3.5-01).

Noble gases and their transport in the atmosphere remain an area of scrutiny by the domain specialist for detecting nuclear test signatures. In the case of the latest nuclear tests by the Democratic People's Republic of Korea, studies demonstrated the nearly full containment of the source. However, due to the complexity of the noble gas transport in the atmosphere and the presence of radioxenon background, no conclusion can be drawn whether a nuclear test signal was recorded at an IMS noble gas system. In fact, scientific experts are still considering data to search for radioxenon signals in background noise to associate radioxenon emissions with all of the announced nuclear tests by the Democratic People's Republic of Korea. Since identifying the source of radioxenon is challenging, experts at the panel "DPRK Nuclear Testing – CTBTO Expertise and Knowledge" advocate special scientific development efforts for enhanced methods to discriminate possible nuclear explosion signals against the strongly varying background.

Among others, the combination of high resolution atmospheric data sets with global meteorological specifications as an input for a regional dispersion model was proposed and evaluated against emissions from nuclear power plants (**T2.4-01**).

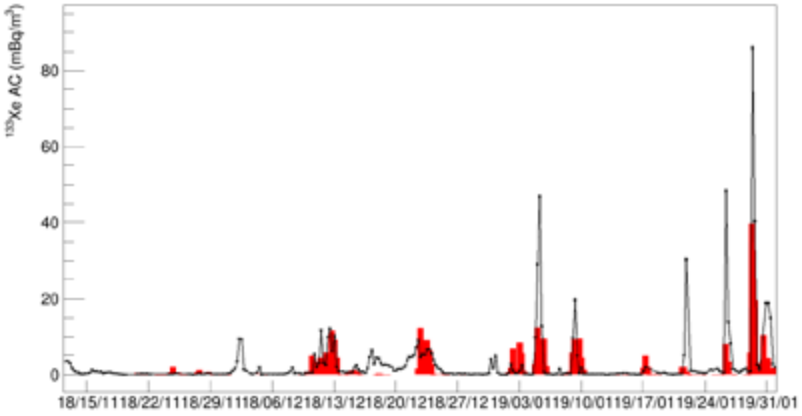


Figure 57. Simulated (red) and measured (black) 133Xe activity concentrations from SAUNA III samples with six-hour collection time, collected in Stockholm, Sweden in 2018. Simulations with atmospheric transport model PELLO, taking into account only the contribution from the Forsmark plant. From A. Ringbom. et al. (T2.4-01).

Medical and industrial isotope production facilities release radioactive isotopes in the atmosphere, which contributes to the global background. Such facilities act as radionuclide sources that must be identified and categorized appropriately in order to mitigate their influence in the search for Treaty-relevant events. An update of the Source Term Analysis of Xenon (STAX) project was presented (**T2.4-06**). Collected data help to advance the understanding of the radioactive xenon civilian source term and hence its possible influence on source characterization. An objective Bayesian computation framework was used to demonstrate the *Source Term Estimation in the Presence of Nuisance Signals* (**T3.5-P62**). This method uses certain free parameters to create a model of background and signal through optimization. The results provide probable values for source magnitude, release time, and release location.

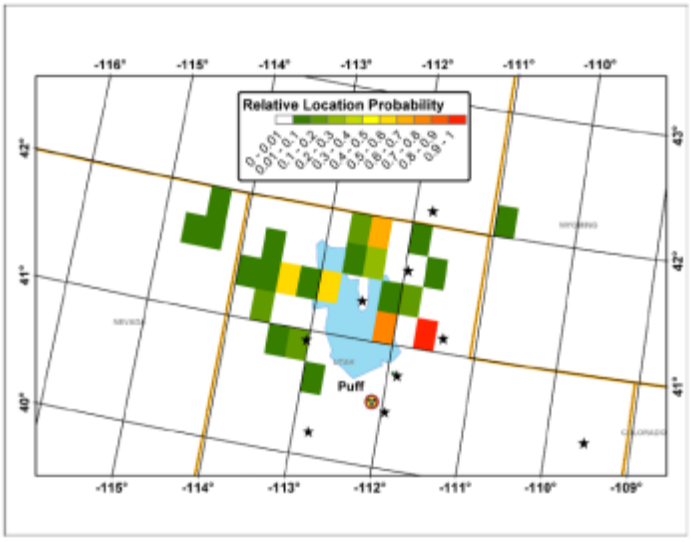


Figure 58. A new algorithm identifies a short-duration release that is confounded by a long term nuisance release from a different location with uncertainty estimates. From B. Schrom et al. (T3.5-P62). Figure source: P.W. Eslinger et al, Source Term Estimation in the Presence of Nuisance Signals, Journal of Environmental Radioactivity 203:220-225, (2019). DOI:10.1016/j.jenvrad.2019.03.022.

The issue of CTBT-relevant signals against a background from other sources is an important topic for OSI as well. It pertains not only to radioxenon but to ^{37}Ar as well. Related to this topic, recent advancements (**T2.4-P25**) have confirmed the correlation of ^{37}Ar and ^{39}Ar during measurement campaigns at historic test sites.

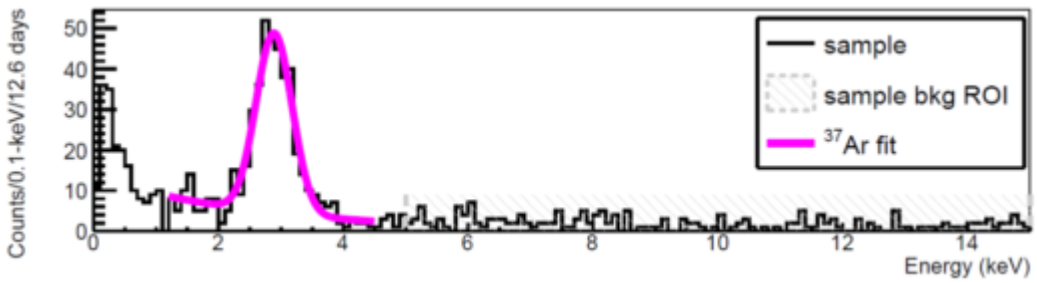


Figure 59. Fractional release of argon from activated rocks and powder show that small amounts of 37Ar are detectable above the atmospheric background, for example as shown in the beta energy spectrum from an obsidian sample. C. Johnson et al. (T2.4-P25).

6.7. Capability, Performance and Sustainment

Relevant Topics
T1.3: Properties of the Ocean
T3.1: Design of Sensor Systems and Advanced Sensor Technologies
T4.1: Network Optimization
T4.2: Systems Engineering
T4.3: Enabling Technologies
T4.4: Performance of the Full Verification System
T5.3: Capacity Building, Education and Public Awareness

Incremental improvements to an already impressive IMS network capability are progressing in a number of areas. Several areas were highlighted, including research being undertaken to better understand the conversion of acoustic water-borne T phase energy to land-based seismic energy to increase the reliability of T phase input for processing and analysis (**T1.3-02**); the development of new infrasound sensors with low self-noise and improved stability in different environmental conditions (**T3.1-P9**); and the development and testing of next-generation noble gas systems that will provide enhanced spatial and temporal resolution (**T3.1-05**). The capability of the IMS network was again demonstrated, this time by observations of the hydroacoustic network and subsequent processing and analysis to assist in the search for the missing Argentine submarine *ARA San Juan* (**T1.3-01, T1.3-03**).

Further development and application of regional seismic travel time, NET-VISA software and methodologies to deal with aftershocks were again at the fore. As has already been demonstrated upon their implementation into the system in the medium term, improved automatic event lists and final event locations are expected, and less analyst time will need to be devoted to large aftershock sequences. In parallel, the Australian National Data Centre reported on progress in generating more reliable automatic bulletins, with the ultimate goal of reducing dependence on full analyst review of data (**T4.4-02**).

The use of the cloud has increased significantly over the past several years and has been considered for National Data Centres (**T4.3-P9, T5.3-P10**). Savings in operational costs have been realized, while at the same time the security of data and applications in the cloud have met stringent stakeholder requirements. The cloud could be seen as a viable platform option for parts of the business of the CTBTO, since it could potentially reduce the expense and complexity of purchasing, configuring and managing information technology hardware and software, but the requirements on deploying extra controls to ensure strong security on a public cloud is yet to be discussed and studied.

The importance of fully engineered complex systems such as the IMS network and IDC software, which is progressing through a re-engineering phase, was emphasized. Results have been delivered in terms of optimization, sustainability and meeting the changing needs and expectations of stakeholders. Advances in the analytics of sustainment data are lending further support to the notion that the sustainment activities of the IMS network should be primarily based on data-driven decisions (**T4.1-03, T4.2-01**). To optimize performance and manage the cost of sustaining the IMS network, further standardization of station equipment was emphasized.

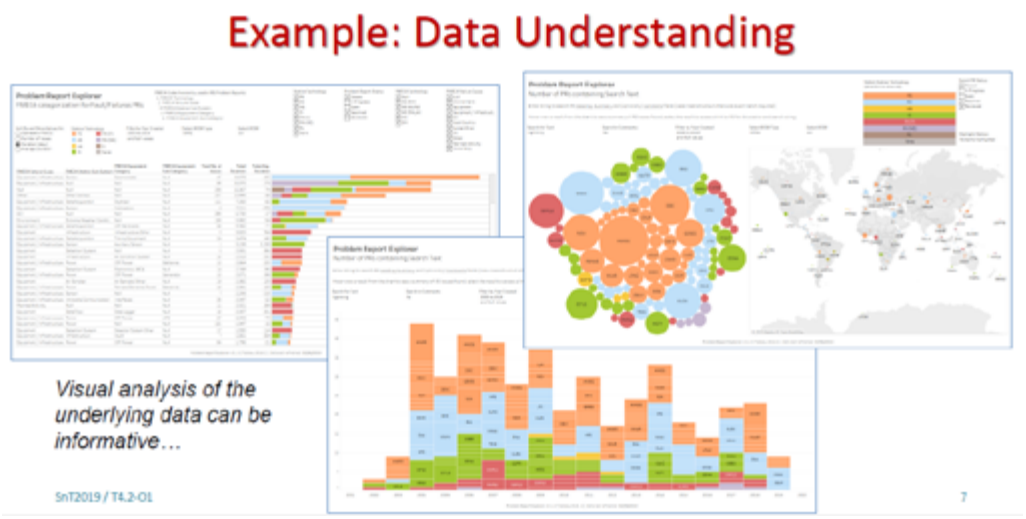


Figure 60. The IMS Analysis Team has already developed several components of an integrated support system for decision making. Building on this earlier work and the lessons learned, the need for a standardized data mining approach to supportability analysis was recognized. Visual analysis of the underlying data can be informative shown in the example., From P. Benicsak and D. Foster. T4.2-01.

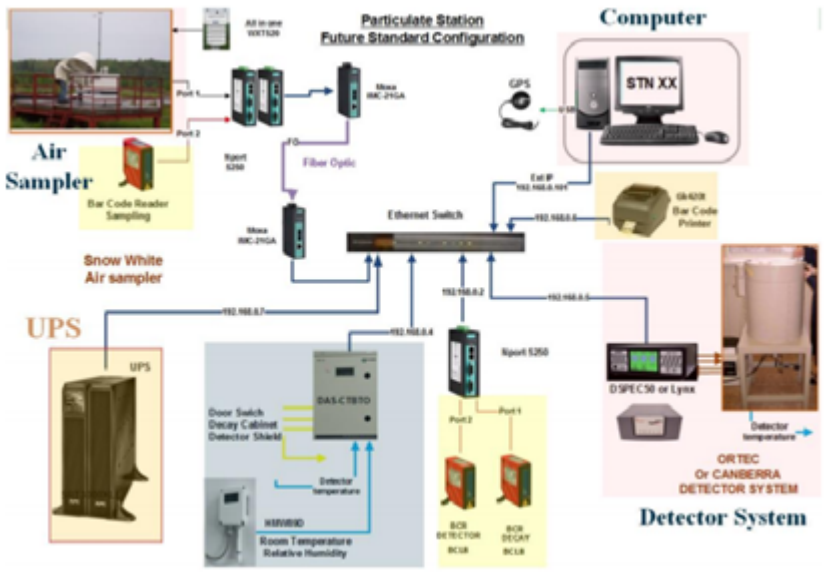


Figure 61. Equipment standardization at manual particulate stations. From W. Hamani et al. (T4.1-P17).

In addition, to strengthen sustainment of the IMS network, a number of approaches and applications were highlighted, including modular design approaches for PTS vaults, wind noise reduction systems and power and communications systems that can be tailored to specific station conditions; advances in state of health monitoring tools; new generations of instrumentation with associated enhanced reliability; and strengthening of the underlying station infrastructure.

6.8. Sharing Data and Knowledge

Relevant Topics
T2.2: Challenges of On-Site Inspection
T4.2: Systems Engineering
T4.3: Enabling Technologies
T4.4: Performance of the Full Verification System
T5.2: Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals
T5.3: Capacity Building, Education and Public Awareness

The uncertainty of potential target objects is one of the main problems in the development of OSI subsurface techniques. Zones of explosive disintegration are described by complicated models with the presence of other disrupted areas including spall zones and common fracturing areas. Active seismics (**T2.2-010**) is an effective technique to describe these complicated models for OSI. New techniques, including microtremor techniques (**T2.2-P8)**, are worthy of mention for future needs in OSI.

The new silicon photomultiplier-based Compton telescope gamma imager (**T2.2-05**) was presented. It can perform a kind of triangulation to work out the distribution of radioactivity along the inside perimeter of a restricted access site.

Interferometric instrumentation that can be mounted on drones at relatively low elevation adds to the potential OSI methods (**T2.2-08**). This technique enables a very dense cloud of observations leading to high spatial resolution. The use of open source data and the low cost of drones are relevant to OSI.

Systems Engineering

The importance of fully engineered complex systems such as the IMS network and IDC software were emphasized. It was noted that sustainment activities of the IMS network should primarily be based on data-driven decisions. Further standardization of the station equipment is necessary in order to optimize performance and manage the cost of sustaining the IMS network (**T4.2-01**, **T4.2-02**, **T4.2-03**).

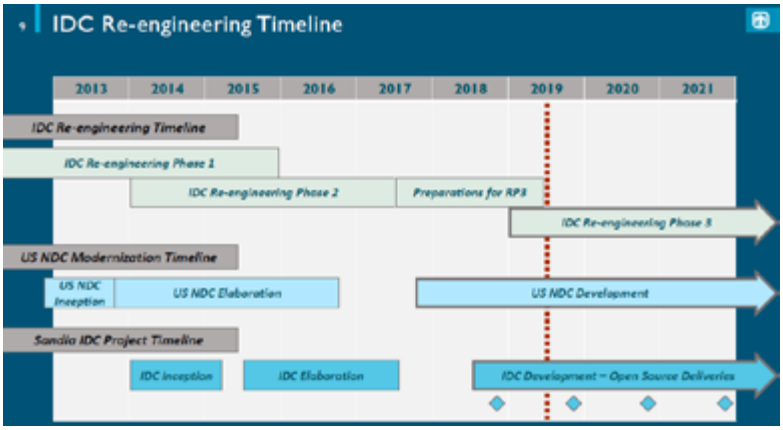


Figure 62. The IDC has begun the development phase of the IDC re-engineering project to improve capabilities and maintainability of the waveform processing system. GMS has substantial overlap with IDC system requirements. The next release (2019) will provide a generic runnable system including basic components for data acquisition, automated processing, and interactive analysis., From J.M. Harris et al. (T4.2-03).

Regarding contributions to issues of global concern, the CTBTO should work at promoting and increasing the use of its data for disaster risk reduction. Many countries require assistance in developing effective warning systems for natural disasters. Such use of CTBTO data would also contribute to the sustainability and expertise of National Data Centres (**T5.2-04**, **T5.2-05**, **T5.2-06**, **T5.2-010**). Therefore capacity building programmes using IMS data and IDC products for geo-hazard training, monitoring and warning activities should become key elements of the long term science and technology activities.

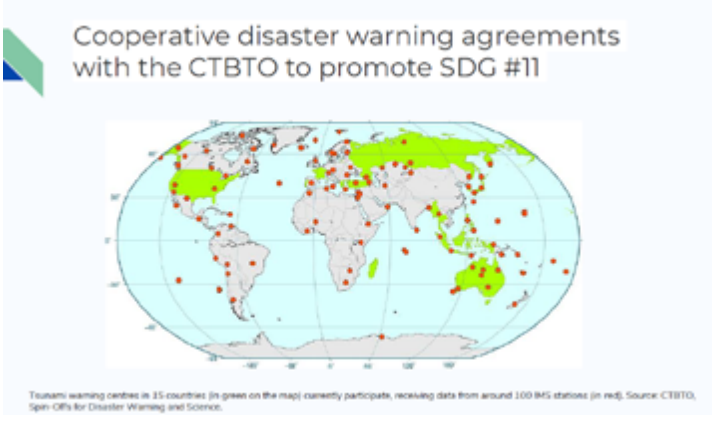


Figure 63. How the IDC can serve as a resource to strengthen risk detection and early warning provisions. From B. Gautam and N. Zhurina. (T5.2-010). Figure source: https://www.ctbto.org/verification-regime/spin-offs-for-disaster-warning-and-science.

Capacity Building, Education and Public Awareness

The CTBTO Youth Group proposed new approaches to the Treaty. The importance of raising public awareness and encouraging the younger generation to learn more about the Treaty through interactive activities and conferences and was emphasized (**T5.3-06**, **T5.3-09**).

Figure 64. The CTBT Science Diplomacy Generation is a diversified capacity building project of the Moscow Engineering Physics Institute aiming to train and nurture the next generation of science diplomacy experts who will address daunting problems facing the Treaty. SnT2019 is an opportunity to introduce the modules of the proposed project, its interdisciplinary teaching methods and a multilingual CTBT glossary created through joint efforts., From E. Tsyvkunova. (T5.3-06).

Figure 65. Nuclear engineering students at the Technological University in Kyaukse, Myanmar., From T. Win. (T5.3-09).

It was also mentioned that civil society organizations, in close collaboration with the CTBTO, should encourage authorities to introduce the CTBTO and its mission into the education system in order to create a culture of peace and to further efforts towards a life without nuclear weapons and nuclear tests (**T5.3-010**).
The relevance of PTS activities such as workshops, training programmes and expert meetings to improve the monitoring and verification regime of the CTBT, to enhance knowledge exchange, to strengthen the engagement of the scientific community and to identify scientific developments was highlighted (**T5.3-011**).

6.9. Policy and Advocacy

Relevant Topics
T5.1: Science in Policy Discussions and Lessons Learned from Other Arms Control Agreements and Arrangements
T5.2: Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals
T5.3: Capacity Building, Education and Public Awareness

SnT2019 continued and built upon emphases in recent conferences on links between CTBT science and technologies and policymaking. A particular focus was placed on the role of the younger generation of scientists and policymakers, on advocacy for the CTBT through science and technology, on the role of women in science and technology, and on ensuring equal access to both science and policy elements of the CTBT among different language communities.

Two panel discussions were held in the French and Spanish languages respectively. These served to highlight the link between multilingualism and multilateralism, particularly in the context of a highly technical Treaty and an international organization with State Signatory stakeholders. The relevance of science and diplomacy approaches was undeniable, and cooperation outcomes were substantially beyond what could have been accomplished in English alone.

A panel discussion on "Women in Science and Technology" focused on success stories of women in science as well as barriers to entry for women in pursuing careers in science, technology, engineering and mathematics disciplines.

The panel discussion "CTBTO Youth Group – Agents of Change for Progress of CTBT Entry into Force" presented how the CTBTO Youth Group has effectively advocated for the Treaty over the course of three years and examined possible initiatives for the years to come.

Under **Topic 5.1, T5.1-01** examined approaches to providing diplomats and policymakers with scientific insight through the prism of the Chemical Weapons Convention, highlighting the need for education and science communication. **T5.1-02** examined how regional views of arms control instruments can differ, from the perspective of South Asia. **T5.1-03** suggested the possibility of adherence by the Democratic People's Republic of Korea to the CTBT, drawing on lessons learned from other arms control instruments.

A panel discussion on "Science Diplomacy: Science Advisors and Arms Control Practice" heard how science is a fulcrum for policy development. Issues examined included how to provide access to good scientific advice, how to encourage policymakers to use advice, how to develop capacity globally and regionally, and how to foster collaboration between scientists and policymakers. The CTBTO as a key example of science-policy dialogue was also discussed.

The panel discussion "Getting the Non-Proliferation and Disarmament Architecture Back on Track" examined the links between the CTBT and the Treaty on the Non-Proliferation of Nuclear Weapons, as well as prospects for the 2020 Review Conference of the Parties to the NPT and the essential role of the CTBT in international nuclear non-proliferation and disarmament.

Under **Topic 5.2, T5.2-02** examined the use of hydroacoustic data for monitoring of ocean phenomena, with a particular consideration of potential applications for SDG 14. **T5.2-03** analysed research on seismicity and active seismic faults, suggesting the potential for seismic hazard maps for use in assessing geothermal potential. **T5.2-04** considered the case of Gunung Anak Krakatau as an example of the potential impact of tsunamis and the use of CTBT data in the context of hazard mitigation. **T5.2-05** examined the potential of the IMS network to monitor active volcanoes at varying scales, with an emphasis on volcanoes in Sicily and Iceland. **T5.2-06** presented the links between the role of CTBT data for emergency response and climate change monitoring with creating support for the CTBT.

The panel discussion "CTBTO and the 2030 United Nations Agenda for Sustainable Development" examined how to strengthen linkages between the use of CTBT data and achievement of the SDGs, as well introducing a CTBTO Youth Group innovation challenge for SDG achievement.

The panel discussion "Civil Applications: The Use of CTBT IMS Data in Support of Disaster Risk Mitigation", discussed concrete examples of how data can contribute to lessening the impact of disaster risk, as well as suggested ways to improve data use for such purposes.

Under **Topic 5.3**, **T5.3-01** described how youth can engage in nuclear non-proliferation through the prism of the CTBT. **T5.3-03** analysed through survey data the experience of women scientists working at the CTBTO and attempted to extrapolate lessons for advancement of women in science. **T5.3-05** presented the work of the National Research Nuclear University MEPhI in education on the CTBT. **T5.3-06** drew out the links between learning on science diplomacy and advocacy for the CTBT. **T5.3-08** highlighted methods of advancing public awareness on nuclear matters. **T5.3-09** focused on raising awareness among students on the CTBT. **T5.3-010** examined the role of civil society in advocacy for the CTBT. **T5.3-011** highlighted the value of CTBTO workshops and training activities as educational products.

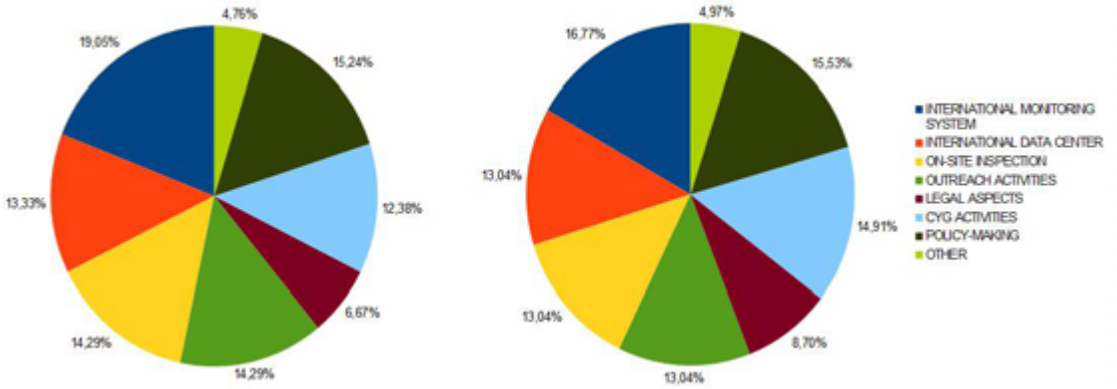


Figure 66. Career preferences among male/female CTBTO Youth Group members in terms of CTBT-related activities., From S. Bukhalina and M. Zadorozhnaia. (T5.3-03).

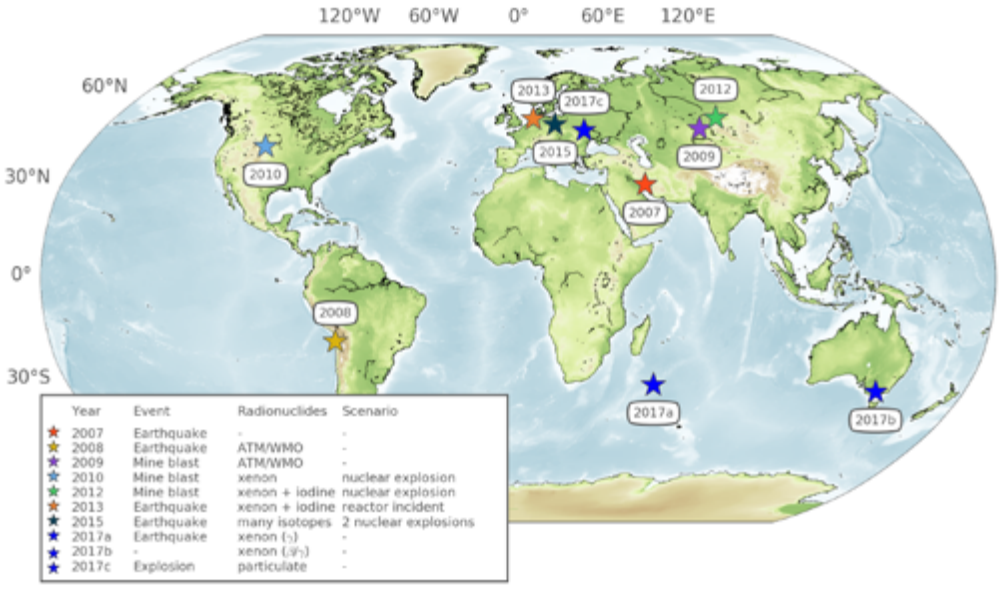


Figure 67. History of NDC preparedness exercises. From J.O. Ross et al. (T4.4-P7).

6.10. Summary of Relevance to CTBTO Activities and Verification Science

The CTBT: Science and Technology 2019 conference featured the scientific and technical maturity of the CTBT verification regime, the interdisciplinary collaboration leading to the continuous improvement of its science and technology base and the essential role of the CTBT in international nuclear non-proliferation and disarmament. SnT events foster partnerships and discussions between the scientific communities, policymakers and diplomats in support of the CTBT and related national needs and enhance geographical and gender representation. Approximately 1200 scientists, experts, practitioners and youth from more than 100 countries attended SnT2019. The main trends that emerged during the conference are reviewed and presented in this chapter of the report and summarized in this sub-chapter.

In the area of Treaty-relevant events, waveform analyses of the announced nuclear tests by the Democratic People's Republic of Korea further raised confidence in the monitoring capabilities of the IMS. On the radionuclide front, scientific experts continue to develop new and enhanced methods that are able to search for more radioxenon signals that still remain hidden in background noise but can be associated with a certain confidence to possible radioxenon emissions originating from one of the six announced nuclear tests by the Democratic People's Republic of Korea. As with any scientific discipline dealing with detection, the accurate spatial and temporal characterization of the background against which one tries to detect a signal of interest is a key aspect that can be particularly challenging.

The potential usefulness of a database of nuclear explosion related signals for training, processing development and testing purposes is widely accepted in the community, and to this end progress is being made towards preserving and making available for research digitized data of historic nuclear explosions.

In the area of OSI, highlights included the presentation of gamma spatial imaging and a new tool for the remote survey of a restricted area from its boundary, based on the tomographic reconstruction of gamma measurements from multiple points of view. The emerging field of OSI triggered by events in complex, dynamic or challenging environments was addressed in a panel discussion. This emerging field will require significant advances in science and technology, as well as knowledge of the dominant environmental phenomena and legal frameworks in order to ensure future readiness for OSIs in locations that are remote, extreme or beyond the jurisdiction of a national authority.

A notable advance in waveform processing was the successful implementation of the Bayesian automatic network processing software NET-VISA in CTBTO operations, where it is used in parallel to traditional methods. Analysts are now able to access the automatic events produced by NET-VISA to complement the set of events presented to them for review and thus improve the automatic scanning procedure. As processing tools evolve and become more sophisticated, it should also be borne in mind that the IMS offers the unique possibility of fusing data from its four different sensor technologies. Advancing data fusion and extending this approach to also include non-IMS technologies may have the potential to improve detection, association and localization performance and at the same time further scientific advances in geophysics.

As in many other areas of computer science and data analysis, there has been increased interest in artificial intelligence and machine learning applications in the CTBTO context as well. The increase in the number of installed IMS sensors is generating significantly large amounts of data. This in turn is beginning to lead to the accelerated development of artificial intelligence and machine learning tools to deal with these data and extract more information and improved statistics. As the processing power becomes more available and economical, the potential of employing machine learning as a useful tool to improve event detection and localization is also increasing, notably with methods such as Bayesian modelling. Such methods have the advantage of allowing complex physics to be taken into account, since they are based on forward modelling. It is important to bear in mind that progress in artificial intelligence and machine learning-based processing needs to go hand in hand with physical understanding. Physical understanding should be incorporated into the automatic processing techniques through accurate modelling and the results reviewed by human analysts in order to maintain confidence in the correct use of such tools.

Waveform cross-correlation methods are showing promise with regard to the improvement of event detection and localization and for the mitigation of challenges posed by large seismic aftershock sequences. More widely, earthquake detections by IMS stations supported advances in earth sciences and the knowledge of geophysical properties on a global, regional and local scale, while providing the key benefit of improving the location accuracy derived by the IMS network. Similarly, hydroacoustic studies of indirect propagation paths reflected by bathymetric features showed the potential to significantly improve event localization by exploiting knowledge of the bathymetry and physical properties of the ocean. Long term data provided by the hydroacoustic network is leading to an increased understanding of how our oceans change with time. System modularity may allow additional science sensors, such as ocean bottom seismometers, temperature probes or current meters, to be added to hydroacoustic stations in the future, enhancing the long term ocean observation capabilities of this segment of the IMS. In the realm of infrasound technology, the synergy between atmospheric observations and modelling with infrasound data analysis demonstrated that there is a strong link between improvements in middle atmosphere weather models and accurate infrasound data analysis and interpretation.

Several SnT2019 contributions highlighted the challenge of ensuring the operational success of the IMS as the focus shifts from network growth to sustainment. Sustainment activities of the IMS network should be primarily triggered by data-driven decisions, with fast issue identification to support effective resource allocation and ensure continued data availability. The importance of station equipment standardization for the optimization of IMS network sustainment was emphasized, as well as the enhanced reliability of new generations of equipment and strengthened station infrastructure. Robust engineering, modularity and sustainment mission planning with probabilistic risk reduction can further contribute to the future sustainment of stations located in harsh environments, such as remote ocean locations.

Overall, the SnT2019 conference demonstrated how the synergy between scientific progress in geophysical sciences and Treaty monitoring drives improvements in both of these areas, producing benefits to science and the CTBT. Expanding the collaboration around IMS data sharing and exploitation with other United Nations bodies such as United Nations Office for Outer Space Affairs, the World Meteorological Organization and the United Nations Framework Convention on Climate Change and initiatives such as United Nations-Oceans or the Sendai Framework for Disaster Risk Reduction is an avenue which offers many opportunities that are still waiting to be harnessed. Further investigating and highlighting the relevance of the CTBT and the scientific and civilian applications of IMS data to the United Nations Sustainable Development Goals is an aspect that should also be pursued further, as it offers the possibility to communicate the relevance of CTBTO work to the States Signatories and to gain further traction towards universalization and ratification of the Treaty.

The need for inclusion and development of expertise through capacity building programmes and scientific and civil applications is a continuous recommendation from the global community. SnT2019 included significant contributions under these themes. A particular focus of SnT2019 was placed on the role of the

younger generation and the CTBTO Youth Group for advocacy in support of the CTBT, on the role of women in science and technology, and on ensuring equal access to the science and policy elements of the Treaty among different language communities. Two language panels, one in French and one in Spanish, highlighted the link between multilingualism and multilateralism, and a panel discussion on women in science and technology provided inspiring stories and suggestions for women pursuing careers in the sciences.

Several contributions stated how in the modern world science is becoming a fulcrum for policymaking, and therefore global and regional capacity building and collaboration between scientists and policymakers are becoming increasingly important. In this sense, effective and authoritative science communication plays a key role in bringing across the CTBT's message among policymakers and the general public. In the modern communication landscape, reaching young audiences in particular and keeping them engaged around CTBT-related themes requires an approach that goes beyond traditional media channels. The CTBTO Youth Group, which continues to grow and was enthusiastically involved in all aspects of SnT2019, from its organization to participation in panel discussions and scientific sessions, occupies a particularly important role, as it encourages the engagement of a new generation of policymakers and scientists who will push the Treaty towards universalization and entry into force.

Appendix 1

Theme 1. The Earth as a Complex System

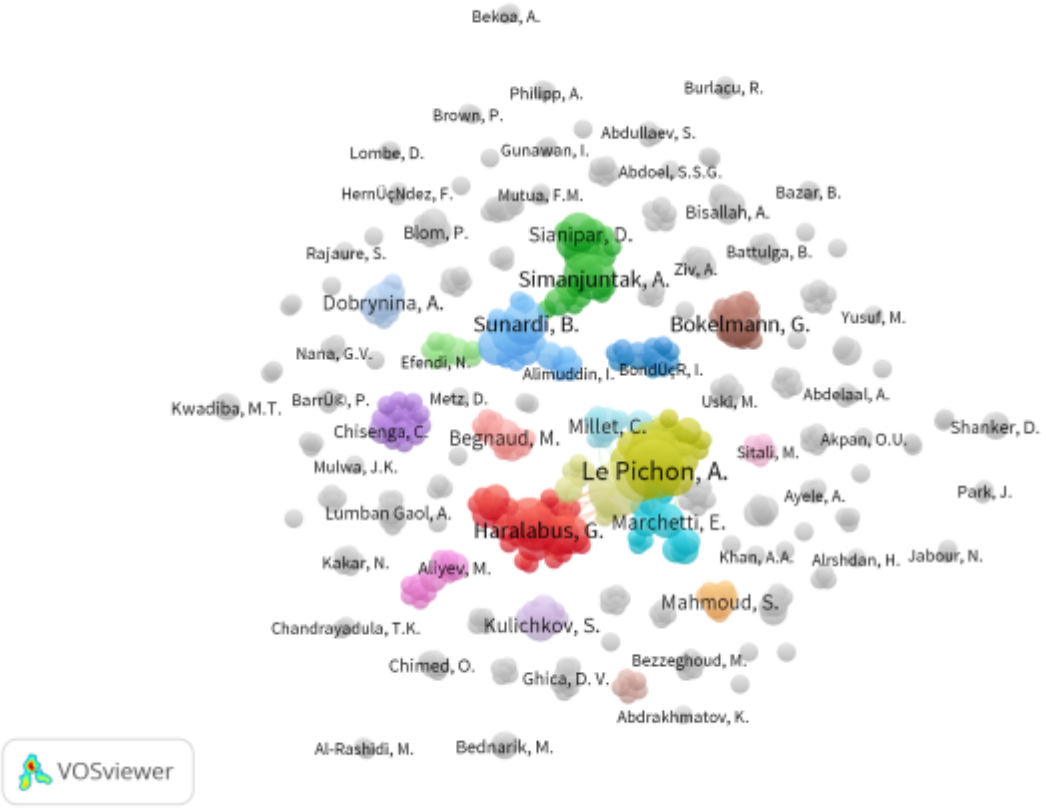


Figure 68. Theme 1. Network Visualization by Authorship based on the Book of Abstracts (173 abstracts, 466 authors, and 108 clusters). CTBTO Library developed this figure using Mendeley and VOSviewer Software[9].

Oral and Poster Presentations

[* indicates that the item is mentioned in Chapter 6]

T1.1 Atmospheric Dynamics

Oral Presentations

*T1.1-01 Application of Advanced Data Assimilation Techniques to Improve Atmospheric Transport and Dispersion Predictions
N. Heath, A. Suarez-Mullins

*T1.1-02 Assessing Middle Atmosphere Weather Models Using Lidar and Ambient Noise: A Case Study for IS26
P. Hupe, L. Ceranna, C. Pilger, M. De Carlo, A. Le Pichon, B. Kaifler, M. Rapp

T1.1-03 Atmospheric Boundary Layer as a Laboratory for Modeling Infrasound Propagation and Scattering in the Atmosphere
I. Chunchuzov, S. Kulichkov, V. Perepelkin, O. Popov, A. Vardanyan, G. Ayvazyan

*T1.1-04 Climate Change Through the Eyes of Radioisotopes
L. Terzi, M. Kalinowski, G. Wotawa, P. Saey, M. Schoeppner, I.T. Hoffman

*T1.1-05 Detection Efficiency of the IMS for Bolides
P. Brown, N. Gi

*T1.1-06 NEMO - A Global Near Real-Time Fireball Monitoring System
T.L.M. Ott, E. Drolshagen, D. Koschny, G. Drolshagen, P. Mialle, C. Pilger, J. Vaubaillon, B. Poppe

*T1.1-07 Recording of Internal Gravity Waves and Infrasound Waves from the Warm and Cold Fronts in Moscow Region
E. Golikova, S. Kulichkov

T1.1-O8 Remote Monitoring Volcanic Eruptions Using IMS infrasound Data
T. Arnal, A. Le Pichon, P. Hereil, E. Marchetti, P. Mialle

T1.1-O9 Temperature and Wind Atmospheric Lidars as Tools for the Validation of Infrasound Propagation Models
A. Hauchecorne, P. Keckhut, S. Khaykin, R. Wing, A. Le Pichon, E. Blanc

T1.1-O10 The Effect of Atmospheric Boundary Layer on the Detected Radionuclides in Kuwait
M. Al-Rashidi, M. Al-Sudairawi

*T1.1-O11 Uncertainties in Numerical Weather Forecasting Models and Infrasound Simulations as Observed by the ARISE Project
E. Blanc, A. Le Pichon, P. Hupe, C. Pilger, P. Keckhut, A. Hauchecorne, J-F. Mahfouf, A. Charlton-Perez, R. Hibbins, P. Espy, G. Stober, G. Baumgarten, B. Kaifler

Poster Presentations

T1.1-P2 Analysis of Multiple Detections of May 2011 Grímsvötn (Iceland) Eruptive Activity at Different IMS Infrasound Stations and Its Correlation with Local Observations
S. Matos, N. Wallenstein, P. Campus

T1.1-P3 Analysis of Multiple Detections of Mount Etna Eruptive Activity at Different IMS Infrasound Stations Compared with Near Source Observations
S. Matos, N. Wallenstein, P. Campus, E. Marchetti, M. Ripepe

T1.1-P5 ARISE Project: Infrasound Monitoring for Civil Applications
E. Blanc, A. Le Pichon, C. Pilger, P. Hupe, L. Ceranna, E. Marchetti, N. Brachet, P. Mialle, P. Hereil, S.P. Näsholm, A. Charlton-Perez, G. Marlton

T1.1-P6 Assessing Middle Atmosphere Weather Models Using Lidar and Ambient Noise: A Case Study for IS02
P. Hupe, L. Ceranna, M. De Carlo, A. Le Pichon, B. Kaifler, N. Kaifler

T1.1-P8 Characterizing Ocean Ambient Noise Using Infrasound Network
M. De Carlo, A. Le Pichon, F. Ardhuin, L. Ceranna

T1.1-P10 CORAL – An Autonomous Middle Atmosphere Lidar in Southern Argentina
N. Kaifler, B. Kaifler, P. Hupe, M. Rapp

T1.1-P11 Estimating Tropospheric and Stratospheric Large-Scale Wind Components Using Infrasound from Explosions
E.M. Blixt, S.P. Näsholm, S.J. Gibbons, T. Kværna

T1.1-P14 IDC Infrasound Technology Developments
P. Mialle and Colleagues

T1.1-P15 Improving Propagation-Based, Stochastic Models for Bayesian Infrasonic Localization and Characterization
P. Blom, R. Waxler

T1.1-P16 Improving the Infrasound Monitoring Capability in Europe Incorporating CEEIN
C. Czanik, D.V. Ghica, T. Sindelarova, U. Mitterbauer

*T1.1-P17 Infrasound Monitoring for Global Climate Model Calibration: A Two-Way Collaboration
C. Millet, F. Lott, A. de la Camara, P. Mialle

T1.1-P18 Infrasound Propagation in Multiple-Scale Random Media Using Surrogate Models
C. Millet, A. Goupy, D. Lucor

T1.1-P19 Large Events Recorded at the IMS Infrasound Network
P. Bittner, J. Gore, D. Applbaum, A. Jimenez, M. Villarroel, P. Mialle

T1.1-P21 Look-Up Tables with Empirical Climatologies for Infrasound Detection, Location, and Characterization of Long Range Volcanic Eruptions
R. de Negri, R. Matoza

T1.1-P22 On the Use of Infrasound Observations from Volcanoes for Improving the Weather Forecasts
P. Vanderbecken, J-F. Mahfouf, C. Millet

*T1.1-P23 Probabilistic Predictions and Uncertainty Estimation Using Adaptively Designed Ensembles for Radiological Plume Modeling
D. Lucas, M. Simpson, G. Pallotta

T1.1-P25 Temporal Variations of the Intensity Spectra of Atmospheric Pressure Fluctuations in Different Frequency Ranges and Their Possible Connection with Climate Change
S. Kulichkov, G. Bush, I. Chunchuzov, V. Perepelkin, E. Golikova

T1.1-P26 The Global and Coherent Infrasound Field: Revisiting the Reprocessing of the Full International Monitoring System Infrasound Data, Part 1: Processing
L. Ceranna, P. Hupe, A. Le Pichon

T1.1-P27 The Global and Coherent Infrasound Field: Revisiting the Reprocessing of the Full International Monitoring System Infrasound Data, Part 2: Examples
P. Hupe, L. Ceranna, A. Le Pichon

T1.1-P28 The Influence of Tropospheric Ducts on Long Range Infrasound Propagation
R. Waxler, M. Willis, C. Hetzer, C. Talmadge, J. Assink, P. Blom

T1.2 Solid Earth Structure

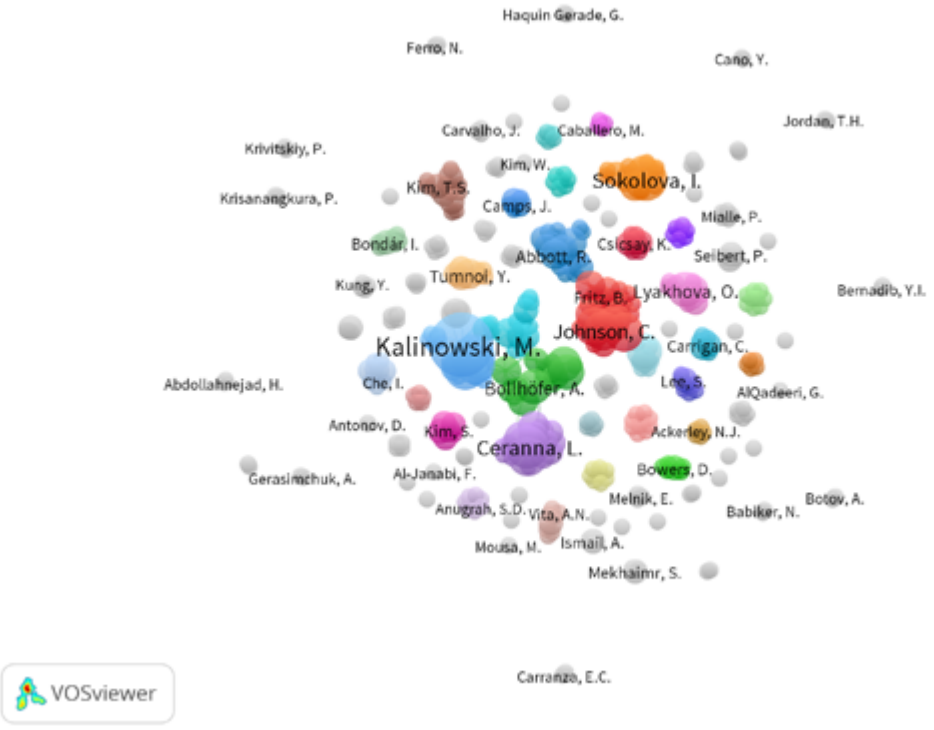


Figure 69. Theme 2. Network Visualization by Authorship based on the Book of Abstracts (166 abstracts, 437 authors, and 94 clusters). CTBTO Library developed this figure using Mendeley and VOSviewer Software.

Oral Presentations

*T1.2-01 3-D Seismic Velocity Model of the Eastern Mediterranean Region Using Body-Wave Tomography
L. Schardong, Y. Ben Horin, A. Ziv, G.H. Wust-Bloch, Y. Radzyner

T1.2-02 Earthquake Swarms and Reactivation of Seismicity Associated with the 2015 Mw 7.8 Gorkha Earthquake in Nepal
L.B. Adhikari, L. Bollinger, B. Koirala, M. Bhattarai, C. Timsina, F. Perrier

T1.2-03 Estimation of Local Seismic Activity by Deterministic Hazard Assessment. A Case Study in North-Eastern of Azerbaijan
G. Babayev, S. Agayeva, L. Telesca, N. Niemi, T. Ismail-Zade, I. Muradi, Y. Aliyev

*T1.2-04 Revised Local- and Regional-Scale Velocity and Attenuation Models for Canada for Improved Earthquake/Explosion Location, Magnitude and Yield Estimates
C. Perry, D. McNamara, S. Myers, M. Begnaud, D. McCormack

*T1.2-06 Updates to the Regional Seismic Travel Time (RSTT) Tomography Model
M. Begnaud, S. Myers, B. Young

Poster Presentations

T1.2-P1 22 New Focal Mechanism Solutions for Shallow Earthquakes and Stress Observations for Bolivia (Plurinational State of)
G.A. Fernandez, M. Nieto

T1.2-P9 An Improved Velocity Model for Routine Hypocenter Location in Central Brazil
J. Carvalho, E. Kissling, L. Barros, M. Assumpção, M. Rocha

T1.2-P12 Analysis of Unusual Seismic Events in Northwestern Madagascar
A.J. Andriamampandry, T. Rakotoarisoa, R. Andrianasolo

T1.2-P13 Are We Able to Detect Viscoelastic Inconsistencies in the Earth?
M. Bednarik, I. Kohút

T1.2-P26 Database from a Seismic Network to Monitor the 2018 Enhanced Geothermal System Stimulation in Espoo/Helsinki, Finland
T. Tiira, G. Hillers, T. Vuorinen, J. Kortström, P. Mäntyniemi, M. Uski

T1.2-P30 Dissecting Hearts of the Continent in Southern Africa Using First P-Wave Tomography Based on Local, Regional, and Mining-Induced Earthquakes
M.T. Kwadiba

T1.2-P37 Flow Plane Orientation in the Upper Mantle under the United States from SKS Shear-Wave Splitting Observations
E. Löberich

T1.2-P43 Heterogeneities of Short-Period S Wave Attenuation Field in the Earth's Crust and Uppermost Mantle of the Eastern Tien Shan
I. Sokolova, Y. Kopnichev

T1.2-P51 Jordan Seismological Networks
M. Al-Qaryouti

T1.2-P53 Lithospheric Scattering and Structure from Teleseismic P Waveforms
I. Gonzalez Alvarez, S. Rost, A. Nowacki

T1.2-P58 Monitoring of Crustal Activities Using Oceanfloor Network System for Disaster Resilience
N. Takahashi, K. Imai, K. Suzuki, T. Nakamura

T1.2-P63 Prediction of Earthquake Hazard in the Northeast India Himalaya
D. Shanker, A. Panthi

T1.2-P68 Present-Day Stress Field in NW Himalaya and Surrounding Regions Based on Inversion of Earthquake Focal Mechanism
S.M. Ali

T1.2-P71 Properties of the High-Frequency Ambient Seismic Field Recorded on a Large-N (N=10,530) Seismic Development in the Vienna Basin
S. Schippkus, G. Bokelmann

T1.2-P73 Recent Seismicity Along the Davie Ridge/Fracture Zone
J.K. Mulwa

T1.2-P80 Seismic Hazard Scenario in Western Himalaya, India
D. Shanker

T1.2-P88 Seismicity of the Okavango Delta Region: Contribution of IMS and Local Stations
O. Ntibinyane, M.T. Kwadiba

T1.2-P95 Sinkhole Process Interpretation Based on Shear Wave Seismic Reflection Results at Ghor Al-Haditha, Dead Sea
H. Alrshdan

T1.2-P102 Stress/Strain State Colouring Method for IMS Data Imaging
M. Bednarik, L. Brimich

T1.2-P107 Tectonic Plates Interactions and Detection Capabilities of the IMS Seismic Stations in the Africa Region
U.O. Madu, A. Bisallah

T1.2-P110 The Caucasus Seismic Hazard
T. Godoladze, R. Gok T. Onur, I. Bondár, M. Dzmanashvili, I. Gunia, N. Tumanova, G. Yetermishli, H. Babayan

T1.2-P118 Updating the Egyptian Earthquake Source Parameters Database
M. Abdelazim A. Metwally, H. Hussein, M. ElGabry, M. Gobashy, M. Khalil

T1.2-P119 Upper Crustal Structure at the KTB Drilling Site from Ambient Noise Tomography
E. Qorbani, I. Bianchi, D. Zigone, P. Kolinsky, G. Bokelmann

T1.2-P120 Upper Mantle Imaging with Surface Wave Diffraction: AlpArray Seismic Network and the Cameroon Volcanic Line
P. Kolinsky, G. Bokelmann

T1.2-P123 Velocity of Seismic Waves in the Earth's Crust and Upper Mantle of the Siberian Platform and Baikal Folded Region According to Underground Nuclear Explosions
A. Dobrynina, V. Sankov, V. Chechelnitsky, K. Burkhard, K. Mackey

T1.2-P124 SALSA3D Software Tools for Model Interrogation, Event Location and Travel-Time
N. Downey, R. Tibi, S. Ballard, J. Hipp, A. Encarnacao, M. Begnaud

T1.3 Properties of the Ocean

Oral Presentations

*T1.3-01 Analysis of Hydroacoustic Signals Associated to the Loss of the Argentinian *ARA San Juan* Submarine
J. Vergoz, Y. Cansi, Y. Cano, P. Gaillard

*T1.3-02 Calculation of Hydroacoustic Propagation and Conversion to Seismic Phases at T-Stations
J. Stevens, J. Hanson, D. Salzberg, P. Nielsen, M. Zampolli, R. Le Bras, G. Haralabus

*T1.3-03 CTBTO's Contribution to the Search of the Missing Argentine Submarine *ARA San Juan*
P.L. Nielsen, M. Zampolli, R. Le Bras, P. Mialle, P. Bittner, A. Poplavskiy, M. Rozhkov, G. Haralabus, E. Tomuta, R. Bell, P. Grenard, T. Taylor, N. Meral Özel

T1.3-04 Hydroacoustic Signatures "Petition" for Social Change: Curating Hydroacoustic Data to Strengthen the Implementation of Environmental Dimensions of the SDGs
K.C.J. Ho

T1.3-05 Distributed Detection Framework and Three-Dimensional Propagation Model for Acoustic Detection of Baleen Whales
N.R. Pinto, T.K. Chandrayadula

T1.3-06 Enabling Technology to Extend Life and Utility of Hydroacoustic Systems
J. Cummins, J. Reardon, S. Meehan, C. Christianson, G. Cekada, R. Elliot

T1.3-07 Monte Carlo Simulation Tool for Maritime Operations Risk Reduction and Enhancement of IMS Hydroacoustic Network Sustainment
M. Zampolli, G. Haralabus, J.P. Stanley, J.B. Mattila, K.L. Williams, S. Dickinson, G.S. Cram, M.J. Harrington

T1.3-08 OOI Cabled Array Winched Profiler Data for Improved Hydroacoustic Analyses
L. Zurk, K. Williams, K. Rosburg, G. Cram, M. Harrington

*T1.3-09 Reducing Ambiguity in Hydroacoustic Triangulation Through Consideration of Three-Dimensional Propagation Features
D. Dall'Osto

Poster Presentations

T1.3-P3 IMS Discrimination Between T-Phases Originating from Volcanic Tremors Versus H-Phases Induced by Volcanic Eruptions in the Northwestern Pacific Ocean
H. Matsumoto, M. Zampolli, G. Haralabus, J. Stanley, J. Mattila, N. Meral Özel

T1.3-P4 Long-Range Ocean Sound Propagation Effects Related to the Search for the Argentine Submarine *ARA San Juan*
P.L. Nielsen, M. Zampolli, R. Le Bras, G. Haralabus

T1.3-P5 Scenario-Based Tsunami Hazard Assessment for Karapathos Island, Southeastern Aegean Sea
L. Dimova, R. Raykova, A. Armigliato, G. Pagnoni, S. Tinti

T1.3-P7 Subspace Detection of Seismic Survey Signals Observed on the IMS Hydroacoustic Network
A. Brouwer, P.L. Nielsen, R. Le Bras

T1.3-P8 Suprapodal Hydroacoustic Observations of Earthquakes Along the Middle American Trench
D. Metz

T1.4 Interaction Among the Earth's Subsystems

Oral Presentations

*T1.4-O1 Atmospheric Events Energy Estimation Based on Seismic Data
Y. Ben Horin

*T1.4-O2 Complex Propagation of Explosion-Generated Infrasound Revealed by the Large-Scale AlpArray Seismic Network
F. Fuchs, F. Schneider, P. Kolinsky, S. Serafin, G. Bokelmann, AlpArray Initiative

T1.4-O3 Modulation of Gas Fluxes at the Soil-Atmosphere Interface Due to Coupled Physical, Chemical and Biological Effects
E. Pili, C. Alibert, P. Barré

Poster Presentations

T1.4-P1 ^{7}Be in South America: Detection by IMS Radionuclide Stations and Possible Applications for Climate and Environmental Studies
R.E. Villarreal

T1.4-P9 Monitoring Seismic Events and Content of Isotopes on Atmospheric Aerosol of Tajikistan
S. Abdullaev, V. Maslov, T. Davlatshoev

T1.4-P10 Observations of Interactions Among Earth's Subsystems from the EarthScope Transportable Array
R. Woodward, K. Aderhold, A. Frassetto, R. Busby, K. Hafner

T1.4-P13 Seismo-Acoustic Observation of the Ocean Swell Sources at BURAR Site
D.V. Ghica, B. Grecu, M. Popa

T1.4-P15 ThunderSeis: Seismic Analysis of Thunder Infrasound
A. Novoselov, F. Fuchs, M. DorningerG. Bokelmann

T1.4-P16 Use of IMS Facilities for Monitoring Hazardous Geophysical Phenomena and Climate Change in the Antarctic Peninsula Region
O. Liashchuk, E. Karyagin, Y. Andrushchenko

Theme 2. Events and Nuclear Test Sites

T2.1 Characterization of Treaty-Relevant Events

Oral Presentations

*T2.1-O1 Infrasound Records Associated with the Western of Yunnan Fireball on October 4, 2017
W. Su

*T2.1-O2 Physical Characterization of Filters from German and Sweden Radiological Monitoring Networks with Ru-106 from 2017
M. Cooke, A. Botti, I.T. Hoffman, W. Zhang, K. Ungar, A. Davies. J. Collins, A. Bollhöfer, J. Kastlander, G. Steinhauser, D. Zok

T2.1-O3 Possibilities to Identify Cavity Due to UNE Using Seismic Wave Fields
J. Kristek, M. Kristeková, P. Moczo, P. Labák, M. Gális

*T2.1-O4 Seismic Full Moment Tensor Analysis of Nuclear Explosions in North Korea
C. Alvizuri, C. Tape

*T2.1-O5 Seismic Spectral Ratios between North Korean Nuclear Tests: Implications for Their Seismic Sources
P. Jin

*T2.1-O6 The 2017 North Korean Nuclear Test - A Comprehensive Multi-Technology Analysis
P.J. Gaebler, L. Ceranna, N. Nooshiri, A. Barth, S. Cesca, M. Frei, I. Grünberg, G. Hartmann, K. Koch, C. Pilger, O. Ross, T. Dahm

T2.1-O7 UK NDC Analysis of IMS Radionuclide Events near to North Korea
M. Goodwin, R. Britton, A. Davies

Poster Presentations

T2.1-P1 A Seismo-Acoustic Analysis of the 2017 North Korean Nuclear Test
J. Assink, G. Averbuch, S. Shani-Kadmiel, P. Smets, L. Evers

T2.1-P4 Applying Radioxenon Isotopic Ratios for Nuclear Explosion Monitoring
I. Ouedraogo, M. Kalinowski H. Gheddou, B. Liu

T2.1-P5 Automatic Computation of MSVMAX Magnitude at the French National Data Center
A. Guilhem Trilla, Y. Cano

T2.1-P6 Candidate Methods for the Implementation of OSI Resonance Seismometry
R. Häfner, M. Walter, M. Joswig

*T2.1-P9 Comparison of the DPRK Aftershocks Observed in 2019 with the Aftershocks Between September 2016 and April 2018
I. Kitov, M. Rozhkov

T2.1-P11 Detection of Nuclear Explosions by Remote Regional Seismic Network
V. Nikulins

T2.1-P12 Determination of Body-Wave Magnitudes of the North Korean Underground Nuclear Test
W. Kim

T2.1-P13 Explosion Monitoring Research at the Nevada National Security Site
J. Bonner

T2.1-P14 Focal Mechanism of 2017 DPRK Nuclear Explosion and Its Collapse Event
H. Xu

T2.1-P15 Identification of Quarry Blasts near BRMAR Seismic Array: An Application of Multichannel Cross-Correlation Detector
K.U. Şemin, T.C. Destici, S. Koçak, Ö. Necmioğlu, M.U. Teoman

T2.1-P16 Infrasound Signals from the 2017 North Korea Underground Nuclear Explosion and the Subsequent Collapse Event
J. Park, B. Stump, C. Hayward, I. Ch,, J. Assink, L. Evers, P. Smets

T2.1-P17 Overview of North Korean Nuclear Tests Based on Data from Modernized Slovak National Networks of Seismic Stations
R. Kysel, K. Csicsay, L. Fojtikova, A. Cipciar, Z. Chovanová

T2.1-P19 Radionuclide Signatures of Molten Salt Reactors
J. Burnett, B. Milbrath

T2.1-P20 Relative Location of DPRK Test Events
T. Van De Mark

T2.1-P21 Relative Location of North Korean Nuclear Tests Using IMS Data: How Do Different Techniques Compare?
J. Dimech, D. Nadri,S. Spiliopoulos

T2.1-P22 Relocation of Seismic Events in South Africa for Ground Truth Identification and Classification
V. Midzi, B. Manzunzu, T. Pule, T. Mulabisana

T2.1-P23 Representation of Complex Seismic Sources by Orthogonal Moment Tensor Fields
A. Juarez Zuñiga, T.H. Jordan

T2.1-P24 Seismological Investigations of the 2017 North Korean Nuclear Test
P.J. Gaebler, A. Barth, L. Ceranna, S. Cesca, T. Dahm, G. Hartmann, N. Nooshiri

T2.1-P25 Source Depth and Characteristics of the DPRK's Nuclear Tests [2006, 2009, 2013, 2016J (01/06/2016), 2016S (09/09/2016) and 2017] Using Regional and Teleseismic Data
S.G. Kim, Y. Gitterman, S. Lee, S. Koh, G.J. Lee, H. Bae

T2.1-P26 Source Time Functions of North Korean Nuclear Tests
A. Ziolkowski

T2.1-P27 Space Borne Optical and Radar Data to Characterize North Korean Nuclear Test 2017
M. Frei, I. Grünberg

T2.1-P28 Summary of Common Exercise (Waveform Portion) at the 6th East Asia Regional NDC Workshop 2018
R.S. Jih, D. Nadri, T.S. Kim, M. Motohashi, E. Dorj, T. Van De Mark, D. Clauter, I. Kitov, W. Allan

T2.1-P29 The Detection of Underground Nuclear Explosions by Natural Signatures
J. Burnett, H. Miley

T2.1-P30 Three-Dimensional Space Analysis of Radioxenon Isotopic Activity Rations for Characterizing a Nuclear Event
K. Yamba, M. Kalinowski, O. Sanogo

T2.1-P31 Towards an Improved Catalogue of Shallow Ground Truth Events in Eastern North America
N.J. Ackerley, M. Kolaj, C. Perry, V. Peci, J. Adams

T2.1-P32 Underground Nuclear Explosions on the North Korean Test Site According to the KNET Network Data
A. Berezina, I. Sokolova, T. Nikitenko

T2.1-P34 Yield Estimates for the DPRK's Sixth Nuclear Test with Radar and Seismic Analysis
T.S. Kim, W. Baek, H. Jung

T2.2 Challenges of On-Site Inspection

Oral Presentations

*T2.2-O1 A Rapid and Non-Destructive Method for Determining In-Situ Uniaxial Compressive Strength (UCS) of Rocks During On-Site Inspections
J.K. Mulwa

T2.2-O2 CHAOS During an OSI (Applying Measurement Restrictions to Sample Characterisation at the BOO)
R. Britton, A. Davies

T2.2-O3 Cs-137 Background Measurement in the Marine Environment of the Asia-Pacific Region to Support Emerging Challenges of On-Site Inspection (OSI) in Seas
Y. Tumnoi, S. Visetpotjanakit, N. Nakkaew, C. Khrautongkieo, R. Suwanklang

*T2.2-O5 Gamma Imaging for On-Site Inspection: Reconstruction of an Extended Source in a Restricted-Access Zone
N. Murtha, L. Sinclair, P. Saull, A. MacLeod, A. McCann

T2.2-O7 How to Develop a Credible Scenario for Large Field Exercises - Scenario Task Force Activities
G. Haquin Gerade, Scenario Task Force

*T2.2-O8 The Potential Use of Interferometric Techniques in the Location and Size Estimation of Suspected Test Sites
G. Suarez, G. Berrocal

*T2.2-O9 Utilization of Unmanned System for Environmental Sampling in CTBT OSI
D. Wu, G. Liu, B. Ye, F. Kuang

*T2.2-O10 UNE's Subsurface Signatures, Detected by Active Seismic Surveys at the Semipalatinsk Test Site
A. Belyashov, V. Suvoro, E. Melnik

Poster Presentations

T2.2-P3 Business Approach to Finish an Unsolved Dilemma of the OSI
M.H. Rahman, Y.I. Bernadib

T2.2-P6 ESI 2007 Earthquake Intensity Scale in Help of CTBT OSI's Verification Regime
F. Audemard

*T2.2-P8 Studying the Suspected Site of Nuclear Test by Using Microtremor Method
W.T.A. Mesaad

T2.2-P15 VNIIA Major Activities Related to the CTBT Technologies
O. Gerasimchuk, G. Zasimov, E. Kremenetskaya, A. Popov, M. Orlov, M. Chernov, O. Tkachev

T2.3 Seismoacoustic Sources in Theory and Practice

Oral Presentations

*T2.3-O1 Analysis Result of DPRK's Nuclear Test Using Korea Meteorological Administration (KMA) Infrasound Network
Y. Jeon, K. Min, Y. Lee, S. Rhee

*T2.3-O2 Analyzing the Reduced Displacement Potentials of DPRK Nuclear Explosions Using Waveform Equalization Technique
C. Saik

T2.3-O3 Data Analysis and Simulations of the Source Physics Experiments: Impact on Explosion Discrimination & Monitoring
S. Ezzedine, O. Vorobiev, A. Pitarka, D. Steedman, A. Cashion, M. Townsend, J. Wagoner, T. Antoun, W. Walter, C. Bradley, J. Bonner, R. Abbott

Poster Presentations

T2.3-P1 A New GT5 Event in a Previously Aseismic Region of the Brazilian Phanerozoic Parnaiba Basin
L. Vieira Barros, M. Sousa de Assumpcao, J. Carvalho

T2.3-P3 Analysis and Modeling of the Infrasound Signals from the 2017 DPRK Nuclear Explosion at IMS Station IS45
C. Pilger, K. Koch

*T2.3-P5 Analysis of the Infrasound Signals from a Bolide Over the Bering Sea
P. Negraru, G. Johnson

T2.3-P6 Complex Seismological Investigations Near Bulgarian Antarctic Base
G. Georgieva, L. Dimitrova, V. Gourev, V. Protopopova, P. Raykova, I. Aleksandrova, I. Popova, D. Dimitrov

T2.3-P9 Detection and Interpretation of Seismoacoustic and Seismic Events at NDC Iraq
Y.H. Shamkhi

T2.3-P12 Distributed Sensing Observations and Modeling of the DAG Series of Chemical Explosions
R. Abbott, R. Mellors, A. Pitarka

T2.3-P13 Estimating Seismic Source Depths Using Body and Surface Wave Observations
R. Heyburn, N. Selby, D. Bowers

T2.3-P16 Hybrid Waveform Modeling for Small-Scale Source Complexity at Teleseismic Distances
M. Pienkowska-Cote, S. Nippress, D. Bowers, T. Nissen-Meyer

T2.3-P17 Implications for S Wave Generation from Subsurface Chemical Explosions Using Large Arrays of Sensors
R. Mellors, A. Pitarka, E. Matzel, W. Walter, T. Chen, C. Snelson, R. Abbott, C. Zeiler, J. Bonner

T2.3-P19 Infrasound Monitoring of Deorbiting Soyuz Crafts on the Territory of Central Kazakhstan
I. Sokolova, A. Smirnov

T2.3-P20 Measurement of Rotational Ground Motions for CTBT
S. Donner, P.J. Gaebler, L. Ceranna

T2.3-P22 Seismic Moment Tensor Inversion for Source-Type Identification
A. Chiang, R. Gok, W. Walter

T2.3-P23 Simultaneous Relocation of the Seismicity of the Pannonian Basin Using Bayesloc
B. Czecze, S. Myers, I. Bondár

T2.3-P24 Source Models and Scattering Origin of Regional Phases from Coda Spectral Ratios
W.S. Phillips, H. Patton, M. Cleveland, C. Larmat

T2.3-P25 Study of Seismoacoustic Signatures of the September 28th 2018 Sulawesi Earthquake
C. Pilger, P. Gaebler, L. Ceranna, A. Le Pichon, J. Vergoz, A. Perttu, D. Tailpied, B. Taisne

T2.3-P26 The Annual Hungarian Seismo-Acoustic Bulletin of Ground Truth Events
C. Czanik, M. Kiszely, P. Mónus, B. Süle, I. Bondár

T2.3-P27 The Baumgarten and Ingolstadt Explosions: Infrasound Observations from Ground Truth Sources in Eastern Austria and Southern Germany
K. Koch, C. Pilger

T2.3-P30 Waveform and Dispersion Modeling Using DPRK Regional Seismograms Recorded by the High Sensitivity Seismic Network of Japan
C. Saikia, A. Jemberie, M. Woods

T2.3-P31 Near-Source Mechanism for Creating Shear Content from Buried Explosions
D. Steedman

T2.4 Atmospheric and Subsurface Radionuclide Background and Dispersion

Oral Presentations

*T2.4-O1 Analysis of High Time-Resolution Observations of Radioxenon Releases from BWRs Compared to Stack Data and Reactor Operation Parameters
A. Ringbom, A. Axelsson, T. Fritioff, N. Brännström, O.H. Grahn, S. Hennigor, M. Olsson

T2.4-O2 Application of Computational Fluid Dynamic in the Atmospheric Dispersion of Radionuclides at Fukushima Disaster
C.E. Bonfim, V. Guimarães Marques de Oliveira, F. Barbosa Ougano, T. Medeiros Silveira Silva

T2.4-O3 Assessment of Temporal Variations of Natural Radionuclides Beryllium-7 and Lead-212 in Surface Air in Tanay, Philippines
P.T.F. Cruz, A.I. Bonga, C. Dela Sada, J. Olivares, F. Dela Cruz, L.J. Palad, A. Jesuitas, E. Cabatbat, T. Garcia, C. Feliciano

T2.4-O4 Contribution of All Nuclear Research Reactors to the Global Radioxenon Emission Inventory
M.Kalinowski, P. Tayyebi, S. Biegalski, M. Lechermann, A. Ringbom

T2.4-O5 Half a Century of Krypton-85 Measurements in the Atmosphere of Central Europe
A. Bollhöfer, C. Schlosser

*T2.4-O6 High Resolution Stack Data from Fission Based Mo-99 Production
J. Friese, J. Burnett, T. Bowyer, C. Doll, B. Deconninck, E. Hoffmann

T2.4-O8 Search for Radioxenon Signals at IMS Stations Possibly Associated with Announced DPRK Nuclear Tests
M. Kalinowski, P. Bourgouin, H. Gheddou, J. Kusmierczyk-Michulec, B. Liu, T. Taylor

T2.4-O9 The Detection of Ar-39 Above UNEs Decades Later as a Signature
B. Milbrath, T. Alexander, J. Fast, B. Fritz, J. Hayes, C. Johnson, R. Kirkham, J. Lowrey, E. Mace, J. McIntyre, K. Olsen, A. Seifert, V. Chipman, M. Townsend

T2.4-O10 Underground Nuclear Explosion Signatures Experiment (UNESE) Phase 2: Gas Migration Studies in a Tunnel Test Location
C. Johnson, T. Alexander, J. Fast, B. Fritz, J. Hayes, R. Kirkham, J. Lowrey, E. Mace, M. Mayer, J. McIntyre, B. Milbrath, K. Olsen, M. Ripplinger, A. Seifert, R. Suarez, L. Zhong, V. Chipman, H. Gang, M. Townsend, K. Wagner

T2.4-O11 Backgrounds, False Negatives and False Positives: Dealing with RN Detection in 2019
T. Bowyer

Poster Presentations

T2.4-P1 Aerosol Dynamics and Dispersion of Radioactive Particles
P. von Schoenberg, P. Tunved, R. Krejci, N. Brännström

T2.4-P2 Application of Source Detective System for a Fukushima Accident
K. Suh, K. Park, B. Min, S. Kim, J. Kim

T2.4-P3 Argon-37 Variability in the Low Troposhere
R. Purtschert, M. Kalinowski, R. Riedmann, J. Fontaine, J. Kusmierczyk-Michulec, H. Gheddou, P. Bourgouin, Y. Tomita

T2.4-P4 Assessment of Radionuclides Present in Atmospheric Aerosol in Dar Es Salaam, Tanzania by Using Gamma-Ray Spectrometry
D.R. Seif, P.B. Nyanda, Y.I. Koleleni

T2.4-P5 Atmosperic Dispersion and Ground Level Deposition of Cs-137 Released from Chernobyl Nuclear Power Plant Accident
E. Bilgic, P. Seibert, A. Philipp

T2.4-P6 Atmospheric Dispersion Assessment of Radioxenon After North Korea's 6th Nuclear Test Using LADAS Model
K. Park, B. Min, S. Kim, J. Kim, M. Yang, K. Suh

T2.4-P10 Atmospheric Dispersion of Radionuclides Originating from Hypothetical Accidents and Normal Operation in Research Reactors and Medial Production Facilities
M. Alessi

T2.4-P13 Atmospheric Transport Modelling for Dispersion Conditions After the DPRK 2017 Nuclear Test and the Origin of Regional Xenon Detections
J.O. Ross, P. Gaebler, L. Ceranna

T2.4-P14 Atmospheric Transport Study of Japan Noble Gas Systems
J. Fast

T2.4-P15 Backward Atmospheric Transport Modelling Coincidence Localization of Single Sources and Repeating Emitters
J.O. Ross, A. Bollhöfer, C. Schlosser, L. Ceranna

T2.4-P16 Characterization and Evolution of Global Xe Background Between 2016 and 2018
M.Y.T.A. Elbahrawy, S. Mekhaimr

T2.4-P20 ECMWF Data Sets as Input for the ATM FLEXPART Prepared by a New Version of the flex_extract Tool
A. Philipp, L. Haimberger, P. Seibert

T2.4-P21 Establishment of the National Baseline Using Data from IDC
P. Krisanangkura, S. Udomsomporn

T2.4-P22 Estimation of the CTBT-Relevant Radionuclides Sources by Ensemble Adjoint Atmospheric Transport Modeling
S. Mekhaimr

T2.4-P23 Estimation of Xenon Background for the IMS Stations Located in the Pacific Ocean
J. Kusmierczyk-Michulec, M. Kalinowski, H. Tatlisu

*T2.4-P25 Fractional Release of Argon from Activated Rocks and Powders
C. Johnson, J. Lowrey, A. Prinke, T. Alexander

T2.4-P26 Global Observations of Radioiodine by the CTBT International Monitoring System
M. Kalinowski, H. Gheddou

T2.4-P27 Global Radioxenon Emission Inventory for 2014 by Normal Operational Releases from Nuclear Power Plants and Medical Isotope Production Facilities
M. Kalinowski

T2.4-P28 Hemisperic Atmospheric Dispersion Analysis of Radionuclides Released from the Fukushima Daiichi Nuclear Power Plant
A. Furuno, H. Terada, K. Tsuduki, M. Kadowaki, H. Nagai

T2.4-P29 How the UK National Data Center Utilises Stack Monitoring Data in Support of the Comprehensive Nuclear-Test-Ban Treaty
A. Davies, R. Britton

T2.4-P30 Impact of CRL Shutdown on CTBTO North-American Noble Gas Stations
J. Baré, P. Bourgouin, J. Kusmierczyk-Michulec, A. Leppänen

T2.4-P32 Impacts of Tropical Climate on Radioactivity Measurement in Particles Collected at the Recently Certified RN65, Thailand
P. Hongpitakpong, T. Itthipoonthanakorn, Y. Tumnoi, M. Sriya

T2.4-P33 Inhalation Dose Assessment of ^{212}Pb and ^{7}Be Using Data of IMS RN65
T. Itthipoonthanakorn, P. Hongpitakpong, M. Sriya, Y. Tumnoi

T2.4-P34 Introducing Geomechanics and Discretion Fracture Capabilities into STOMP to Understand the First 10-100m of UNE Signal Transport
J. Lowrey, M. White, C. Johnson, M. Rockhold

T2.4-P35 Inverse Modelling Applied to the Xe-133 Background
P. De Meutter, A. Delcloo, J. Camps, C. Gueibe

*T2.4-P36 Investigation of Emission of ^{37}AR from All Nuclear Research Reactors Worldwide
M. Kalinowski, P. Tayyebi

T2.4-P37 Investigation of Specific Historical Radioxenon Background Detections in the IMS
C. Gueibe, J. Camps, P. De Meutter

T2.4-P38 Isotopic Signature of Radioargon Released from the FRM-II Reactor
J-E. Fontaine-Lagrand, R. Purtschert, A. Bollhöfer, C. Schlosser, G. Böhm, C. Strobl, A. Heise, G. Kirchner

T2.4-P39 Magmas in Nuclear Cavities and Their Potential Effects on the Source Term and Its Migration
E. Pili, C. Carrigan, Y. Sun, M. Cicconi, D. Neuville

T2.4-P40 Measurement of Radioargon and Radioxenon in Soil Gas
J. Kastlander, M. Aldener, A. Axelsson, T. Fritioff, C. Söderström, A. Ringbom, R. Purtschert

T2.4-P41 Medical Isotope Production in Argentina: Status of the Construction of Ra-10 Research Reactor
E.E. Quintana

T2.4-P44 Noble Gas Signature Adsorption in a UNE – Bridging the Gap Between Laboratory and Field Scale Models
J. Lowrey, C. Johnson, M. Rockhold, J. Fast, B. Milbrath

T2.4-P46 Progress Over 2014 Baseline on the Match Between Observations and Simulations of Radioxenon Concentrations at IMS Stations
H. Gheddou, M. Kalinowski, J. Kusmierczyk-Michulec, P. Bourgouin

T2.4-P49 Radionuclides Monitoring Along the Brazilian Coast
F. Da Costa Fernandes

T2.4-P52 Statistical Study of the Atmospheric Background and Anomalous Values of the Radioxenon Activity Concentrations at Some IMS Stations
S. Guernelli, G. Ottaviano, M. Scagliarini, A. Rizzo, F. Padoani, M. Kalinowski

T2.4-P54 The Characteristic Release of Noble Gases from an Underground Nuclear Explosion
C. Carrigan, Y. Sun, M. Simpson

T2.4-P56 Trends in Worldwide Background of CTBT-Relevant Xenon Isotopes Based on IMS Data
H. Gheddou, M. Kalinowski

T2.4-P57 Validation Study of the Flexpart -WRF Model with Episode of Xe-133 Releases and Detections in Europe
M. Schoeppner, M. Kalinowski, J. Kusmierczyk-Michulec, P. Bourgouin

T2.5 Historical Data from Nuclear Test Monitoring

Oral Presentations

*T2.5-O1 Digitization and Analysis of Printed Seismograms from Aftershocks of the Novaya Zemlya Explosion on October 27, 1973
C.F. Hellesen, L.K. Persson, S. J. Gibbons

T2.5-O2 Noble Gases Release After Underground Nuclear Explosions
Y. Dubasov

T2.5-O3 Using Satellite Imagery to Map Russia's Underground Nuclear Test Site on Novaya Zemlya
A. Pellegrino

Poster Presentations

T2.5-P1 A Catalogue of Nuclear Test Explosions Recorded by Slovak National Network of Seismic Stations
M. Šugár, R. Kysel, K. Csicsay, Z. Chovanová, L. Grajcarová

T2.5-P2 A Comprehensive Central Asia Seismological Bulletin
K. Mackey, K. Abrams, A. Berezina, E. Pershina, N. Mikhailova, I. Sokolova, B. Bekturganova, S. Murodkulov, Z. Ilyasova

T2.5-P3 Detectability of the UNE Wigwam by Radionuclides Stations of Today's IMS
B. Milbrath, J. Burnett, P. Eslinger

T2.5-P4 Digitalization of Soviet Era Peaceful Nuclear Explosion Seismograms from Regional Stations
K. Burkhard, A. Dobrynina, K. Mackey

T2.5-P6 Discrimination of Nuclear Explosions and Earthquakes at Regional Distances for the Lop Nor Test Site According to the KNET Network Data
A. Berezina, I. Sokolova

T2.5-P7 Historical Records of Nuclear Explosions in Archives of the Institute of Geophysical Research
D. Bekbulatova, N. Mikhailova, I. Sokolova

T2.5-P8 New Stage of Works on Nuclear Explosions Historical Record Digitization
N. Mikhailova, R. Kemerait, I. Sokolova, I. Aleschenko

T2.5-P12 Waveforms from Nuclear Explosions (WFNE)
R.D. Lewis, V. Oancea, P. Piraino, Y. Kung

Theme 3. Verification Technologies and Technique Application

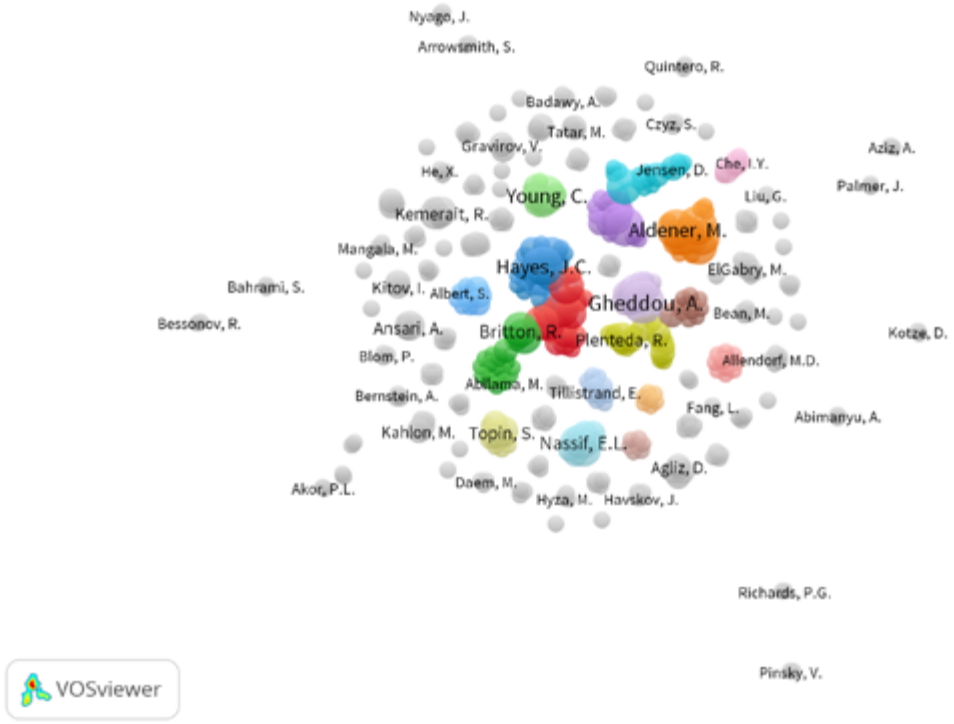


Figure 70. Theme 3. Network Visualization by Authorship based on the Book of Abstracts (175 abstracts, 450 authors and 100 clusters). CTBTO Library developed this figure using Mendeley and VOSviewer Software.

T3.1 Design of Sensor Systems and Advanced Sensor Technologies

Oral Presentations

*T3.1-01 Description and Results from a Feedback Digital Infrasound Detector System
C. Guralp

*T3.1-02 Establishment of a Network of Political and Scientific Cooperation Between CTBTO and the Great Lakes Region to Contribute to Sustainable Development
D. Birimwiragi Namogo

*T3.1-03 Estimation of Antineutrino Registration as a Method of Monitoring Nuclear Explosions
V. Grichuk, R. Bessonov

*T3.1-04 Exploiting the Tailorable Nanoporosity of Metal-Organic Frameworks for In-Situ Identification of Radioisotopes
M.D. Allendorf, P. Doty, T. Wang, A. Benin, J. Greathouse

*T3.1-05 High Sensitive Xe Measurements
Y. Popov

*T3.1-06 High Throughput Argon-37 Field System
J.C. Hayes, K. Silvers, C. Aalseth, T. Alexander, H. Back, M. Foxe, L. Lidey, J. Mendez, D. Stephenson, R. Suarez, G. Whyatt

*T3.1-07 How Useful Are (Quantum Technology) Gravity Measurements for On-Site Inspection?
D. Boddice, G. Tuckwell, N. Metje

*T3.1-08 Seismically Cued Antineutrino Detectors Have Limited Potential to Monitor Nuclear Explosions
R. Carr, J.R.F. Dalnoki Veress, A. Bernstein

T3.1-09 The Feasibility of Using MEMS Technology for Monitoring Large Earthquakes
A. Ansari, E. Karkooti

*T3.1-O10 Using the Existing Telecommunication Optical Fiber Cables as Underwater Seismic Events Detectors
Y. Pashkov

Poster Presentations

T3.1-P1 A Differential Highly Sensitivity Sensor for Accounting of Seismic Devices Instrumental Thermal Noise
V. Gravirov, K. Kislov, D. Likhodeev

*T3.1-P3 A New Process Design for Compact Radioxenon Separation System
A. Monpezat, A. Cagniant, O. Delaune, V. Thomas, S. Topin

*T3.1-P5 Antineutrino Detectors: An Evaluation of Their Use for Monitoring of Nuclear Explosions
M. Foxe, T. Bowyer, J. Orrell, B. VanDevender

T3.1-P6 Application of Optimal Filtering to Take into Account the Influence of Baric and Temperature Fluctuations of the Seismic Instrument and the Environment
V. Gravirov, K. Kislov

T3.1-P7 Applying an Anti-Coincidence System Plastic-HPGe to Lower the MDA of Radioxenon Measurement
F. Rossi, P. Bartolomei, R. Lorenzelli, S. Salvi, A. Rizzo, C. Telloli, D. Mostacci

*T3.1-P9 Calibration of Infrasound Sensors in a Long-Term Field Study
B.J. Merchant, G. Slad, R. Rembold

*T3.1-P10 Characterization of the Microbarometer's Sensitivity to the Environment
P. Vincent, S. Denis, A. Hue, G. Rouille, L. Leclair

T3.1-P12 Deployment of Portable Infrasound Array in Costa Rica
H. Villalobos Villalobos, R. Quintero

T3.1-P14 Development of a Mobile Radiation Detection System
I. Miakota, E. Bystrov, V. Kozhemyakin

*T3.1-P15 Development of a New Compact Photon/Electron Detector for Radioxenon Measurement
V. Thomas, O. Delaune, S. Topin

T3.1-P16 Development of an Electrostatic Precipitator System for Radionuclide Particle Collection
M.E. Swanwick, A.B. Chepko, S. Stokes, C. Devoy, P. Magari

T3.1-P17 Distributed Fiber Optic Seismic Sensors with Seismic Noise Floor Performance
C. Minto

*T3.1-P18 Experimental Setup and Results of Xenon Sorption Characteristics Research for a Number of Adsorbents
M. Chernov, D. Ergashev, O. Gerasimchuk, N. Goryacheva, M. Orlov, V. Probylov, N. Sidorov, A. Simutin, D. Timofeev, O. Tkachev, V. Udalov

T3.1-P20 Future of Aerosol Radionuclide Monitoring
H. Miley, J. Burnett, A.B. Chepko, C. Devoy, P. Eslinger, J. Forrester, J. Friese, L. Lidey, S. Morris, B. Schrom, J. Smart, S. Stokes, M.E. Swanwick, G. Warren

T3.1-P22 Hyper-Sensitive Gamma Spectrometry – Approaching the Ultimate Limit
R. Britton, A. Davies

*T3.1-P25 Investigating New Detection Mediums for Atmospheric Radioxenon Measurements
A. Farsoni, S. Czyz, H. Gadey

T3.1-P27 Next Generation Low-Power HPGe Gamma-Ray Spectrometer to Improve IMS Particulate Radionuclide Station Reliability
S. Kreek, M. Burks, O. Drury, G. Kim

T3.1-P28 Project PIM: A Low-Cost Mobile Seismo-Acoustic Sensor for Geophysical Deployments
O.F.C. den Ouden, C. Oudshoorn, J. Assink, L. Evers

T3.1-P30 Radiation Detection for OSI - A Study of Non-He-3 Neutron Detectors
M.C. Bornhöft, T. Köble, O. Schumann, M. Risse, H. Friedrich, W. Berky, W. Rosenstock

T3.1-P31 Radioactive Gas Metrology at NPL and the Development of Short-Lived Gas Standards
S.J. Bell, M. Abilama, T. Bacquart, A. Boso, S. Collins, F. Farrow-Dunn, P. Ivanov, S. Jerome, Y. Morimoto, N. Roberts, B. Russell, Y. Sakakibara, P. Salvador-Castineira, K. Sasaki, R. Shearman, T. Shibutani, Y. Toriyabe

*T3.1-P32 Radioxenon Collection Using Synthetized Xenon-Adsorbing Material for Nuclear Test Monitoring
S. Kreek, S. Sangiorgio

*T3.1-P33 Report on SPALAX-NG Validation Tests and Performances
S. Topin, G. Le Petit, T. Philippe, A. Cagniant, O. Delaune, P. Gross, G. Douysset, C. Moulin

*T3.1-P34 Results from a 6-Month Acceptance Test of the SAUNA III - Prototype
A. Ringbom, A. Axelsson, T. Fritioff, J. Kastlander, H. Olsson, M. Aldener

*T3.1-P35 SAUNA-CUBE: The First Prototype for a Noble Gas System Adapted for an Array-Network
A. Ringbom, M. Aldener, A. Axelsson, T. Fritioff, C. Hellesen, L. Karlkvist, J. Kastlander, H. Olsson, H. Berglund, V. Höglin, O. Petterson

T3.1-P36 Status of Infrasound and Seismic Metrology at CEA
F. Larsonnier

T3.1-P37 Status of the Stack Monitor for the Stax Project
M. di Tada, R. Pino, I. Scarinci, E. Nassif, R. Sagarzazu

*T3.1-P38 Study of Materials for Improved Adsorption of Xenon at IMS Radionuclide Stations
C. Gueibe, J. Rutten, J. Camps, R. Plenteda

T3.1-P39 Testing of Cosmic Veto for RASA Background and MDC Reduction
E. Tillistrand, B. Hosticka, G. Shipman, M. Wright, G. Kline, R. Hong

*T3.1-P41 The Gas Processing System of SAUNA CUBE
M. Aldener, T. Fritioff, J. Kastlander, L. Karlkvist, A. Axelsson, H. Olsson, C. Hellesen, A. Ringbom

T3.1-P42 The Güralp Affinity as a Replacement for the DM24SXAM
E.M. Passey

T3.1-P43 The Radiation Dose Monitoring Network System in Coastal Area
S. Hirota, Y. Hiroshi

T3.1-P44 Three Future Filters for IMS Radionuclide Particulate Operations
N.H. Hermanspahn, B. Nadalut, A. Tarasov, R. Plenteda

T3.1-P45 Towards Disaster Mitigation on Earthquakes and Tsunamis Using Off Shore Real Time Monitoring Data
Y. Kaneda, N. Takahashi, T. Hori

T3.1-P46 Ultra-Sensitive Measurements of Large-Volume Radioxenon Samples Using an Ultra-Low-Background Proportional Counter
H. Seifert, C. Aalseth, E. Edwards, M. Foxe, B. Fulsom, E. Mace, M. Panisko, K. Thommasson

*T3.1-P47 Unmanned Aerial Vehicles in On-Site Inspection: New Techniques for Gamma Spectroscopy Survey
L. Sinclair, C. Chen, R. Fortin, A. McCann

*T3.1-P48 Updated Results from Long-Term Infrasound Sensor Comparison
D. Fee, S. Albert, R. Rembold, B.J. Merchant, G. Slad, C. Szuberla, J. Helmericks, G. Tytgat, L. Blom, A. Winkelman, H. Buurman

T3.1-P49 Xenon International
J.C. Hayes, M. Cooper, W. Harper, M. Panisko, J. Slack

T3.2 Laboratories Including Mobile and Field Based Facilities

Oral Presentations

*T3.2-O1 Investigations of the Characteristics of Installation for the Measurement of Low Activities of ^{37}Ar Based on the Detection of Liquid Argon Scintillation
S. Pakhomov, T. Kuzmina, G. Shakhetov

*T3.2-O2 More Sensitive Measurements that Radionuclide Laboratories Can Do for Special Studies
A. Davies, R. Britton, J. Burnett, H. Miley

*T3.2-O3 Sample Throughput Improvements for the U.S. Noble Gas Laboratory
M. Foxe, M. Mayer, J. Mendez, J. Slack, T. Bowyer, I. Cameron, M. Cooper, J. Hayes, L. Lidey

Poster Presentations

T3.2-P1 Accuracy of Particulate Sample Analysis with a BEGe Detector
M.M. Rapetsoa, D. Kotze

*T3.2-P2 Developing a Laboratory-Based Beta-Gamma Coincidence Detection System
M. Goodwin, A. Davies, R. Britton, P. Regan, S. Bell

T3.2-P4 Efficiency of Ion Exchange Columns for Precipitation Sampling
C. Söderström, J. Kastlander, P. Lagerkvist, S. Jonsson

*T3.2-P5 Further Development of the SAUNA-FIELD System for Rapid Deployment and Improved Operation
M. Aldener, T. Fritioff, L. Karlkvist, J. Kastlander

T3.2-P7 Radioxenon Spiked Air for Field Testing
M. Watrous, M. Aldenar

T3.2-P9 Status and Results of Xenon Proficiency Test Exercises
H. Gohla, N. Ìnoue, N. Hermanspahn, R. Plenteda

T3.3 Remote Sensing, Satellite Imagery and Data Acquisition Platforms

Oral Presentations

T3.3-O1 Continuous and Unattended Spectroscopic Operation and Analysis with the Mirion Data Analyst
J. Zickefoose, B. Huckins, D. Sullivan, T. Anderson

T3.3-O2 International Radiation Monitoring Information System (IRMIS)
S. Mukhopadhyay, F. Baciu, G. Saluja, J. Segarra

Poster Presentations

T3.3-P4 Applying Multispectral and Hyperspectral Imagery Analysis to Monitor and Verify Front-End Uranium Production **Y**
G. Liu

*T3.3-P5 Comparison of Satellite Earth Observation and Seismic Data to Analysis the Effect of Nuclear Tests in 2017 North Korea
M. Yanis, A. Jihad, M. Marwan, N. Ismail

*T3.3-P7 Design and Construction of an OSI Airborne Techniques Simulator
K. Szalay, A. Bablena, G. Bércesi, L. Kovács, J. Deákvári, F. Sillinger, S. Takács, D. Tóth, M.A. Nasri, A. Collinson, G. Malich, A. Rowlands

*T3.3-P8 Improvements to the Standard Station Interface (SSI) Software: State of Health and Authentication with ECDSA
V. Miljanovic, J. Marty, J. Mattila, N. Meral Özel

*T3.3-P10 Potential Ways for Optimization of Multispectral Including Infrared (MSIR) Imaging for On-Site Inspection (OSI)
I. Markov, D. Sagaradze

T3.3-P11 Several Key COTS Equipments' Potential Application to CTBTO OSI
X. He, X. Ge, P. Li

T3.4 Augmented Reality and Fusion of Data from Different Monitoring Technologies

Oral Presentations

*T3.4-O1 Recreating and Exploring the DPRK Nuclear Test Site in 3D to Calculate Possible Overburdens for Detonations
J. Palmer, N. Selby

Poster Presentations

T3.4-P1 Data Fusion of Electromagnetic and Infrasound Measurements
E. Lipshtat, M. Kahlon, M. Kushnir

*T3.4-P2 Detection and Interpretation of Explosive Events by Seismic and Infrasound Networks of Ukraine
O. Liashchuk, Y. Andrushchenko, L. Kolesnykov, L. Liashchuk

T3.4-P3 Detection and Location of an Earthquake Using Seismic, Infrasound and Hydroacoustic Data: A Case Study of Botswana
U.O. Madu, A. Bisallah, O. Eromosele

T3.5 Data Analysis Algorithms, Artificial Intelligence, Big Data and Deep Learning

Oral Presentations

*T3.5-O1 A Methodology to Establish Bayesian Detection Limits for Radionuclide Monitoring
G. Manificat

*T3.5-O2 A Semi-Automatic Method for Cepstral Depth Estimates for Sequences of Shallow Events
R. Kemerait, I. Tibuleac, M. Capuano, D. Stayt

*T3.5-O4 Can High-Precision Methods of Seismic Monitoring for Earthquakes and Explosions Find Application for Broad Areas?
P.G. Richards, D.P. Schaff

*T3.5-O5 Continuous Assessing of the Reviewed Event Bulletin with Waveform Cross Correlation
M. Rozhkov, I. Kitov

*T3.5-O7 Identification of Repeating Seismic Events Using Diffusion Maps
Y. Bregman, N. Rabin, Y. Ben Horin

*T3.5-O9 Machine Learning for Emulation of Seismic-Phase Travel Times in 3-D Earth Models
S. Myers, D. Jensen, N. Simmons

*T3.5-O10 NET-VISA: Evaluation of Event Location Performance Compared to SEL3, and NEIC PDE
I. Bondár, N. Arora, R. Le Bras

T3.5-O11 Peak Identification in EDS Measurements Using Multiple Subset Sum Problem Formulation
M. Maiza

*T3.5-O12 Recent Improvements on the Broadband Seismic Network of Iran (Implementing Tuned Seiscomp3 and Automatic Online Moment Tensor Inversion)
S. Soltani Moghadam, G. Javan Doloei

T3.5-O13 Statistical Analysis to Advance Common Understanding on SAUNA False Positives Hypothesis
R.D.N. Mulunda, H. Gheddou, M. Kalinowski, B. Liu

*T3.5-O14 The Machine-Learning Tool NET-VISA from Cradle to Adulthood - The Next Generation System of the IDC and the SnT Process
R. Le Bras, N. Arora, N. Kushida, P. Mialle, I. Bondár, E. Tomuta, S. Laban, M. Villarroel, B. Vera, A. Sudakov, S. Nippress, D. Bowers, S. Russell, T. Taylor

*T3.5-O15 Unified Implementation of NCC Analysis Algorithms for Both Current and Next Generation Beta-Gamma Coincidence Based Noble Gas Systems
H. Gheddou, M. Kalinowski

T3.5-O16 Machine Learning to Categorize Radionuclide Spectra
T. Edwald

Poster Presentations

T3.5-P1 A Demonstration of the RKF Solution Method for Multi-Physics Analysis of Radionuclides Evolved in Nuclear Testing
G. Sjoden

T3.5-P2 A New Analysis Method for Beta-Gamma Radioxenon Spectra, Including Improved Calculation of Decision Limits
A. Ringbom, A. Axelsson

T3.5-P3 A New Approach for Calculating 1D Local Velocity Model Using Particle Swarm Optimization Technique
S. Soltani Moghadam, M. Tatar

T3.5-P4 A New Blind Deconvolution Approach for the Separation of Seismic Waves
H. Saylani

T3.5-P5 A Novel Approach for Signal Sparse Time-Frequency Representations
V. Sucic, I. Volaric, G. Bokelmann, R. Le Bras

T3.5-P6 A Semi-Automatic Method for Extraction and Interpretation of Reflection Green's Functions from Ambient Noise and Signal, for IMS Seismic Station Crustal Reflector Characterization
I. Tibuleac, M. Woods, J. Dwyer, R. Kemerait

T3.5-P7 A Simplified Fuzzy ARTMAP Neural Network Based-Approach for Seismic Signal Discrimination Between Earthquakes and Quarry Blasts
E.H. Ait Laasri, E-Sï. Akhouayri, A. Atmani, D. Agliz

*T3.5-P9 Analyzing Seismic Explosion Records Using SEISAN
P.H. Voss, T.B. Larsen, L. Ottemöller, J. Havskov

*T3.5-P11 Applying Waveform Correlation to Aftershock Sequences Using a Global Sparse Network
A. Sundermier, R. Tibi, C. Young

*T3.5-P12 Automatic Characterization of Phase Type at Three-Component Seismic Stations Using Neutral Networks
R. Hofman

T3.5-P13 Automatic Machine Learning Methods for Analyzing Radixenon Isotopes Spectra
S.S. Azimi, H. Afarideh, V. Dost Mohammadi

*T3.5-P14 Automatic Systems for Accurate Tracking of Aftershock Sequences
S.J. Gibbons, T. Kværna

T3.5-P15 Bayesian Approach to Localization of Atmospheric Release with Demonstration on the Case of Ruthenium-106 Release in 2017
O. Tichy, V. Smidl, M. Hyza

*T3.5-P16 Can Artificial Intelligence Help Detect Nuclear Explosions?
I. Scarinci

T3.5-P18 Comparing REB and SSEB (IDC Products) with Other Seismic Data Centers
W. Olimat

*T3.5-P19 Comparison of Pick-Based and Waveform-Based Event Detectors for Local to Near-Regional Distance Data from Utah
C. Young, S. Heck, R. Brogan

T3.5-P20 Contribution of Kazakhstan's Stations of the International Monitoring System into Global and Regional Monitoring
A. Mukambayev, N. Mikhailova, A. Smirnov

*T3.5-P22 Detecting Low Magnitude Seismic Events Using Convolutional Neural Networks
R. Forrest, J. Ray, C. Young

T3.5-P25 Detection Performance of Dynamic Correlation Processors Using De-Noised Signal Space-Spanning Templates
D. Dodge

T3.5-P26 Developing a Deployable, Flexible Radionuclide Analysis Pipeline
M. Goodwin, R. Britton, A. Davies

T3.5-P28 Discrimination Between Nuclear Explosions and Natural Earthquakes
S. Elkholy, H. Moussa, M. ElGabry

T3.5-P29 Disturbing Incidents Signal Character Analysis in Nuclear Explosion Infrasound Detection
X. Pang, J. Teng, Y. Cheng, X. Cheng

T3.5-P30 Dynamic and Agnostic State of Health (SOH) Analysis Tools for Noble Gas Systems
R. Suarez, I. Cameron, J. Hayes, D. Keller, R. Wilson

T3.5-P31 Enhancement on the Algorithm of Characterization Limits of the Net Count Calculation Method for Low Counts of IMS Beta-Gamma Coincidence Noble Gas Samples
B. Liu, T. Muramoto, M. Kalinowski, H. Gheddou

T3.5-P32 Exploiting Bayesian Inference Priors to Form Synthetic Waveform Events or to Validate Events Formed by Automatic Processing
N. Kushida, R. Le Bras

T3.5-P33 Global and Local Scale High-Resolution Seismic Event Catalogs for Algorithm Development and Testing
C. Young, L. Linville, R. Brogan, A. Katherine

*T3.5-P35 Improvements of Phase Detection and Identification Using 3C Array Processing
C. Labonne, Y. Cano, O. Sèbe

T3.5-P36 InfraPy – An Open Source Signal Analysis Toolkit for Infrasound Research
P. Blom, O. Marcillo, J. Webster

*T3.5-P37 iNSPIRE: iNtegrated Software Platform for the Interactive REview - The First Release Features for Beta-Gamma Coincidence Based Noble Gas Data
H. Gheddou, M. Kalinowski, J. Baré, A. Leppänen, S. Moreno, C. Pires, J. Wang

T3.5-P38 Joint Processing of Seismic and Infrasound Signals from Mining Blasts
M. Yedlin, I. Kitov, M. Rozhkov

T3.5-P39 Learning About Small-Scale Atmospheric Structures Through Recurrent Infrasound Events
C. Millet, B. Ribstein, S.P. Näsholm

T3.5-P41 Long-Term Infrasound Monitoring of Volcanic Activities of Kyushu Region in Japan
H.I. Lee, I.Y. Che, G.Y. Kim

T3.5-P43 Matrix Operation of the Net Count Calculation Method for Beta-Gamma Coincidence Spectrum Analysis of IMS Noble Gas Samples
B. Liu, T. Muramoto, M. Kalinowski, H. Gheddou

T3.5-P44 Mel Cepstrum Techniques for Event Identification
R. Kemerait, I. Tibuleac

T3.5-P45 Multilayer Neural Network Architecture Optimization and Performance Amelioration for Seismic Signal Classification Using Genetic Algorithms
A. Atmani, E.H. Ait Laasri, E-Sï. Akhouayri, D. Agliz

T3.5-P46 Optimization Algorithm for Synergy of CTBT Verification Techniques in Addressing IMS and OSI Tasks
A. Rogovoi

T3.5-P48 RASA Filter Jam Detection Algorithms
D. Bustillo, J. Volle, J. Tran, N. Al-Alami, E. Tillistrand, M. Wright

T3.5-P50 Reduction of Wind Noise Impact Based on the Use of Data from a Weather Station in Recording Infrasound Signals at IS43
I. Rybin

T3.5-P51 RNIAC: A Cloud-Based Approach of the Radionuclide National Data Center (NDC) in a Box Software (RNIAB)
S. Laban

T3.5-P52 RSTT Validation Studies in the Middle East, Central Asia and the Caucasus
I. Bondár, R. Gok, S. Myers, I. El-Hussain, W. Abdulnaby, H. Zahran, A. Berezina, T. Godoladze

T3.5-P53 Scientific Evaluation of the Benefits of Increase in Resolution for IDC's ATM Tools and Launching Interface
D. Morton, D. Arnold, P. Bourgouin

T3.5-P54 SeiscomP3 iLoc Integration Applied to Array Processing
B. Weber, I. Bondár, D. Rößler, J. Becker

T3.5-P56 Seismic Phase Identification with Deep Learning in Frequency Domain
M. Salam

T3.5-P57 Sensitivity Analysis and Disaggregation of Recent Seismic Hazard Assessment in Egypt
H.M.G. Farghly, M. El-Hadidy, A. Badawy

*T3.5-P58 Sensitivity of a Bayesian Source-Term Estimation Model to Spatiotemporal Sensor Resolution
D. Jensen, D. Lucas, K. Lundquist, L. Glascoe

T3.5-P60 Simulations of Gamma Ray Spectra of Fission Samples
O. Aviv, A. Lipshtat, S. Vaintraub

T3.5-P61 Source Spectral Discrimination Between Shallow Earthquakes and Quarry Explosion in Northern of Egypt
A. Sami, M. El Gabry, H. Hussein, I. Korrat

*T3.5-P62 Source Term Estimation in the Presence of Nuisance Signals
B. Schrom, P. Eslinger, J. Mendez, H. Miley

T3.5-P63 Source Term Estimation Using Multiple Isotopes in Atmospheric Samples
H. Miley, P. Eslinger, J. Lowrey, B. Schrom

T3.5-P65 Spectral Region-of-Interest Methods Used in Net Count Calculations
M. Cooper, J. Ely, J. Hayes, D. Keller, M. Mayer

T3.5-P67 Stack Data Processing Pipeline
M. Auer, S. Hellman, J. Friese, B. Schrom, T. Bowyer, L. Metz, C. Doll

T3.5-P68 Study of Variants for Seismic Data Pre-Processing Which Are Not Leading to Significant Losses of Information that May Be Needed
K. Kislov, V. Gravirov

T3.5-P71 The Application of Multi-Criteria Synthetic Method in Discrimination of Nuclear Explosions from Earthquakes
Z. Liu

T3.5-P72 The Challenge of Quantitative Comparison and Quality Assessment of IDC Waveform Bulletins
A. Ansari, E. Moradian

T3.5-P73 The Identification and Determination of Small Peaks and the False Positive Alarm in RN Particulate Spectra Analysis
J. Wang

T3.5-P74 The Iterative Processing Framework: A New Paradigm for Automatic Event Building
R. Tibi, A. Encarnacao, S. Ballard, C. Young, R. Brogan

T3.5-P75 The STAX Project. A New Data Source to Aid in Treaty Monitoring
J. Friese, J. Burnett, T. Bowyer, L. Metz

T3.5-P77 Toward Reliable Certainty for Seismic Processing Tasks with Deep Learning
L. Linville, N. Downey, C. Young

T3.5-P79 Towards Real-Time Association of Infrasound Events Using Full-Wave Modeling
M. Bertin, C. Millet, J. Vergoz

T3.5-P80 Using Spectral Ratios to Discriminate Between Low-Magnitude Earthquakes, Explosions and Mining Events in Canada
M. Kolaj, N.J. Ackerley, D. McCormack, J. Adams

T3.5-P82 When Can the Combination of Seismic and Infrasound Data Improve Event Location?
S. Arrowsmith, J. Park

Theme 4. Performance Optimization

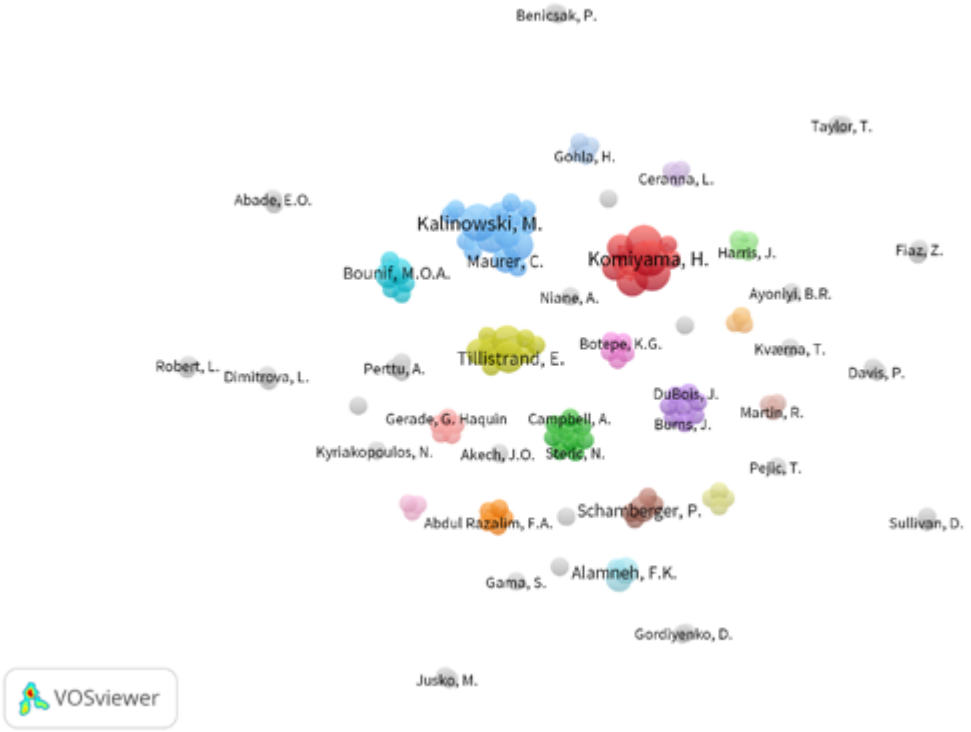


Figure 71. Theme 4. Network Visualization by Authorship based on the Book of Abstracts (53 abstracts, 138 authors, 41 clusters). CTBTO Library developed this figure using Mendeley and VOSviewer Software.

T4.1 Network Optimization

Oral Presentations

T4.1-O1 Adaptable Turnkey Solution for Infrasound Station
R.J.Y. Colbalchini, C. Bednarowicz, P. Schamberger

4.1-O2 Latest Development of the Standard Station Interface Calibration Module
Y. Sid Ahmed, M. Moumouni Kountche, V. Miljanovic, S. Bereza

*T4.1-O3 More Mission Less Money - How to Effectively Optimize Your Network Through Total Life Cycle Management
S. Poindexter, D. Merker, R. Martin

Poster Presentations

T4.1-P2 Bulgarian NDC and Network – New Achievements and Challenges
I. Popova, L. Dimitrova

T4.1-P9 Geodynamic Network of Seismic and Volcanic Monitoring OVSICORI-UNA a Possibility of Data Integration with the Costa Rica National Data Center (NDC-Cr)
H. Villalobos Villalobos

T4.1-P10 Geography Information System Capabilities: GeoEvent Method to Improve Network Optimization of CTBTO Operation Data
B.R. Ayoniyi

T4.1-P13 Implementation of a QA/QC Programme for Noble Gas Monitoring in the IMS Network
B. Wernsperger, H. Gohla, V. Popov, R. Plenteda

T4.1-P14 Implementing Process Oriented Knowledge Management: Lessons Learned from an Application in the OPCW
M. Galindo Arranz, L. Robert

T4.1-P15 IMS Station Management in Argentina
M.A. Fernandez

T4.1-P16 Infrasound Detection Capability Improvement on Noise Reduction System
A.S. Pantin

T4.1-P17 Key Factors that Improved Data Availability at IMS RN Stations
W. Hamani, N. Mascarenhas, A. Wiens, C. Johannsen, H. Tatlisu, H. Komiyama, N. Meral Özel

T4.1-P18 Maintenance Visit to Radionuclide Station FJP26 and Auxiliary Seismic Station AS031/MSVF
C. Johannsen, N. Mascarenhas, H. Komiyama, N. Meral Özel

T4.1-P19 Major Upgrade at IS41 Villa Florida, Paraguay
S. Stefanova, P. Martysevich, N. Mascarenhas, H. Komiyama, N. Meral Özel

T4.1-P20 New High Quality VBB Borehole Sensor Upgrades and Additional Atmospheric Sensors at Global Seismographic Network (GSN) Stations
K. Hafner, P. Davis

T4.1-P23 Parallel Processing in the GDMS Analysis Pipeline
D. Bustillo, J. Volle, J. Tran, E. Tillistrand, M. Wright

T4.1-P24 Power Quality and Generator Monitoring
E. Tillistrand, N. Al-Alami, B. Hosticka, G. Kline, M. Wright

T4.1-P27 Seismic Station Control
M. Chikh, S. Bourouis, M.O.A. Bounif

T4.1-P28 Site Selection for Seismic Broadband Station Installation (CGS Seismic BB National Network)
M. Chikh, R. Bensalem, E.H. Oubaiche, M.O.A. Bounif, D. Bouziane

T4.1-P31 The New Botswana Seismological Network (BSN): Developments in Detection of Seismic Events in Southern Africa and Beyond
O. Ntibinyane, M.T. Kwadiba, K.G. Botepe, J. Maritinkole, R. Simon

T4.1-P33 Next Generation Power Systems of CTBTO'S International Monitoring System (IMS)
M. Jusko, J. Robertson

T4.2 Systems Engineering

Oral Presentations

*T4.2-O1 A New Approach to Supportability Analysis for the IMS, Based on the Cross-Industry Standard Process for Data Mining (CRISP-DM)
P. Benicsak, D. Foster

*T4.2-O2 FaultNet: A Deep-Learning Framework for Data-Gap Analysis
J. Dickey, R. Pena, R. Richards

*T4.2-O3 Geophysical Monitoring System (GMS) Development for IDC Re-Engineering
J.M. Harris, K. Rivera, J. Burns, J. Coram, J. DuBois, L. Kidd, R. Prescott, C. Young

T4.3 Enabling Technologies

Poster Presentations

T4.3-P2 CTBTO Link to the ISC Database
D. Storchak, K. Lentas, J. Harris, G. Csontos

T4.3-P6 Improved Method for the Testing and Verification of the Sierra Instruments 620S Mass Flow Meter
G. Kline, B. Hosticka, E. Tillistrand, M. Wright, S. Little

*T4.3-P9 NDC in the Cloud: Example of Performing Seismic Processing in the Cloud
G.A. MacLeod, J. MacCarthy, O. Marcillo

T4.3-P10 Quantifying the State of Health of a Detection System Remotely with LabPulse
J. Zickefoose, D. Sullivan

T4.3-P11 Temporary Installation of Seismo Wave MB3d With Raspberry Pi at Nanyang Technological University
D. Whilldin, A. Perttu, B. Taisne

T4.4 Performance of the Full Verification System

Oral Presentations

T4.4-O1 3rd ATM Challenge 2019
C. Maurer, J. Kusmierczyk-Michulec, J. Baré, M. Kalinowski, P. Bourgouin

*T4.4-O2 International Monitoring System's Detection and Screening Capability in Australia
T. Pejic

T4.4-O3 Near Real-Time Monitoring of the IMS Event Detection Capability
T. Kværna

Poster Presentations

T4.4-P2 An Assessment of XSEL Bulletin as Produced Through the Cross Correlation Technique
F.K. Alamneh, G. Graham

T4.4-P3 Build Up Exercises to Validate OSI Capability Development
G. Haquin Gerade, J. Kozma, S. Holen, S. Summers, A. Collinson

T4.4-P5 Effective Management of OSI Equipment and Software
A. Rowlands, A. Campbell, P. Labák, G. Malich, M.A. Nasri, C. Smith, A. Lobo, O. Shabelnyk, N. Steric

T4.4-P6 High-Density Configuration Experiment of Noble Gas Measurement Systems in Japan
G. Beziat, M. Kalinowski, N. Ìnoue, J. Kusmierczyk-Michulec, J. Baré, H. Gheddou, P. Bourgouin, Y. Yamamoto, Y. Tomita, Y. Kijima

T4.4-P7 National Data Centre Preparedness Exercise 2017 - Exploring Real IMS Data for Casual Connections
J.O. Ross, N. Gestermann, L. Ceranna

T4.4-P8 Quality Assessment of REB Through Comparison with NEIC Bulletin for the Month of September 2018
F.K. Alamneh, G. Graham, E. Jonathan

T4.4-P9 Quantifying Uncertainties and Confidence Level in ATM Simulations
C. Maurer, D. Arnold, P. Bourgouin

T4.4-P10 Quantifying Uncertainties in the Atmospheric Modelling (ATM) Simulations Resulting from Different Emission Time Resolution
J. Kusmierczyk-Michulec, B. Deconninck, M. Kalinowski, E. Hoffmann

T4.4-P11 Successes in Improving Data Availability to RN Station with Long Term Issues
W. Hamani, N. Mascarenhas, A. Wiens, C. Johannsen, H. Tatlisu, H. Komiyama, N. Meral Özel

T4.4-P13 The CTBTO/PTS Operations Centre
M. Villagran-Herrera, T. Taylor

Theme 5. CTBT in a Global Context

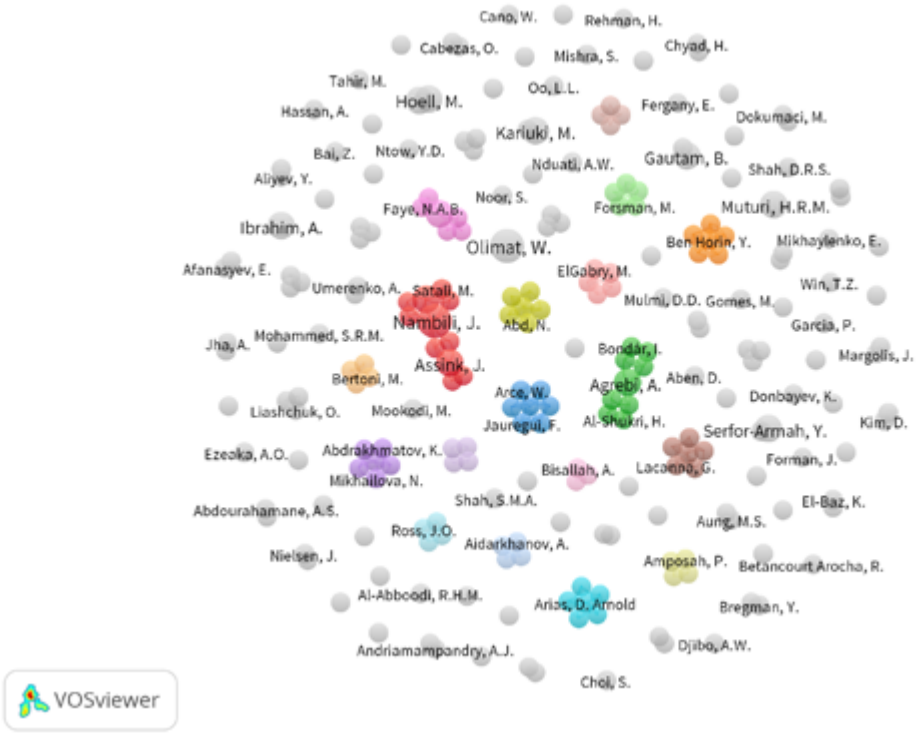


Figure 72. Theme 5. Network Visualization by Authorship based on the Book of Abstracts (132 abstracts, 238 authors and 119 clusters). CTBTO Library developed this figure using Mendeley and VOSviewer Software.

T5.1 Science in Policy Discussions and Lessons Learned from Other Arms Control Agreements and Arrangements

Oral Presentations

*T5.1-O1 Chemistry and Diplomacy: The Provision of Scientific Advice for Disarmament and Non-Proliferation Treaty Organisations
J. Forman

*T5.1-O2 Comparative Assessment of CTBT with International Arms Control and Disarmament Treaties: Strengths and Limitations of Science in Enforcement and Addressing Security Driven Actions
A. Firdous, U. Nizamani

*T5.1-O3 North Korea and the CTBT
E.M. Ifft

Poster Presentations

T5.1-P4 Leveraging the CTBT's Verification Provisions for Promoting Entry-Into-Force
M. Hoell, Y. Woo

T5.1-P5 On-Site Inspection: A Multidimensional Example of Science Diplomacy
A. Zargham, J. Nielsen

T5.1-P7 Testing Customs: The CTBT and Customary International Law
B. Gautam

T5.1-P8 The Development of Arms Control Agreements and Arrangements
S. Choi

T5.2 Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals

Oral Presentations

T5.2-O1 CTBTO for UN 2030: Empowering Diplomacy through Science in South Asia
R. Neog, A. Jha

*T5.2-O2 CTBTO IMS Contribution to SDG: 14 Life Below Water
I.V. Kursenko, J. Andriamampandry

*T5.2-O3 Feasibility Assessment for Geothermal Potential in Las Trincheras - Mariara, Venezuela
K.C. Ramirez Loaiza, M. Schmitz, H. Rendon

*T5.2-O4 Hazard Mitigation Analysis of the Anak Krakatau Eruption and Its Tsunami (22 December 2018)
K. Retno Dewi

*T5.2-O5 Infrasound Monitoring of Active Volcanoes at Local and Regional Scale
E. Marchetti, A. Le Pichon, M. Ripepe, P. Campus, J. Vergoz, G. Lacanna

*T5.2-O6 Amplifying the Impact of CTBTO Data for Emergency Response and Climate Change Monitoring
R. Wang, J. Margolis

T5.2-O8 Renewable Energy and Sustainable Development in the Light of Environmental Security
S.R.M. Mohammed

T5.2-O9 The Catastrophic Failure of the Iron-Ore Tailings Dam: The Worst Environmental Disaster in Brazil
B. Neri, L.V. Barros, J. Carvalho

*T5.2-O10 The CTBTO and Goal 11: Using the IDC to Make Cities Safer and More Inclusive Through Disaster Preparedness Laws (CTBTxSDGs Innovation Challenge)
B. Gautam, N. Zhurina

T5.2-O11 The Invisible Link Between the Sendai Framework for Disaster Risk Reduction and CTBT
Ö. Necmioğlu, G. Wotawa, A. Michelini, G. Iley, D. Arnold Arias, G. Forlenza

Poster Presentations

T5.2-P1 Activities of the Ghana Nuclear Data Centre (NDC)
Y. Serfor-Armah

T5.2-P4 Contributions to Issues of Global Concern such as Disaster Risk Mitigation
A. Ouedraogo

T5.2-P6 CTBT Technology for Securing SDG 6: Ensure Availability and Sustainable Management of Water and Sanitation for All
A.D. García Vazquez

T5.2-P17 Integration of the IMS Waveform Technologies for Tsunami Early Warning: A Perspective from Venezuela and the Caribbean
A.I. Martínez González

T5.2-P22 Modern Seismic Network Development in Iraq
R. Gok, H. Al-Shukri, H. Mahdi, W. Abdulnaby, N. Abd, T. Onur

T5.2-P24 Operational Readiness of CTBT Hydroacoustic Stations in Achieving Sustainable Development Goal 14
U.O. Madu, A. Bisallah, A. Chad Chinaemere

T5.2-P28 Recent Seismic Activities in Ghana: The Role of the National Data Centre (NDC)
P.E. Amponsah, Y. Serfor-Armah

T5.2-P29 Remote Sensing Earthquake Ground Motions Using Seismo-Acoustic Coupled Signals
S. Shani-Kadmiel, J. Assink, L. Evers

T5.2-P38 Swedish Biodiversity in Time and Space
E. Karlsson, M. Forsman, J. Kastlander, C. Söderström, P. Stenberg

T5.2-P45 The WHO and the CTBTO: Joint Initiatives to Address Air Pollution in the Cities **Y**
A. *Umerenko*, V. Korotchenko

T5.2-P47 Tsunami Risk Assessment in South-Eastern Mediterranean
M. ElGabry, H. Hassan, C. Frischknecht, H. Hussein, A. Salama

T5.2-P48 Urban Seismic Risk Evaluation for Georgia
N. Tsereteli, O. Varazanashvili, Z. Gogoladze, T. Mumladze

T5.3 Capacity Building, Education and Public Awareness

Oral Presentations

*T5.3-O1 CTBT and Role of the CYG in the Korean Peace and Denuclearisation Process
M. Nurzhan

*T5.3-O3 Integration Women Technicians in CTBTO
S. Bukhalina, M. Zadorozhnaia

*T5.3-O5 NRNU MEPhI as an Educational Site for Relevant CTBTO Problems Solving
A. Nesterenko, I. Drozdov

*T5.3-O6 Nurturing the Science Diplomacy Generation (SDG) to Advance the CTBT
E. Tsyvkunova

*T5.3-O8 Raise the Nuclear Awareness for the Public Across Culture
A.R. Ismuharto

*T5.3-O9 Raising Public Awareness Among Students About CTBT in Nuclear Age
T.Z. Win

*T5.3-O10 Role of Civil Society Organizations for Education and Public Awareness
M.I. Rabiou, A.S. Abdourahamane

*T5.3-O11 The Intrinsic Value of CTBTO Workshops, Training Programs, and Expert Meetings
J. Mackby

Poster Presentations

T5.3-P1 20 Years of Participations in CTBTO Activities
W. Olimat

T5.3-P2 Awareness Activities Related to CTBT Undertaken by HANEA
A.W. Djibo

T5.3-P3 Awareness of the Radionuclide Monitoring Technology for Myanmar's Students
Zin Wai Myint

T5.3-P6 Capacity Building in Central Asia to Monitor the CTBT
N. Mikhailova, K. Abdrakhmatov, J. Schweitzer, I. Aristova, A. Berezina, S. Mykkeltveit

*T5.3-P10 Cloud Platform as Instrument to Enhance Capabilities of Remote Users (Data Processing and Training)
L. Kolesnykov, R. Synytsky, O. Liashchuk

T5.3-P17 CTBT-SDGs-Innovation-Challenge: Building Resilient Communities Through CTBT Science Information Sharing
A. Jerkins, J. Nambili, J. Assink, N. Titus

T5.3-P18 CTBTO Educational Programme and Sustainable Development Goal 5 in Nigeria
A.O. Ezeaka

T5.3-P22 Engaging Young Generation: The Case of Ural Federal University in Russia
E. Mikhaylenko

T5.3-P26 Estimation of Ionizing Radiation Risk and Their Effects as a Method of Approach to Data Products
E. Gea Izquierdo

APPENDIX I

Appendix 2

Panel Discussions

CTBT: Science and Technology in a Changing World

Moderator
Sanam Shantyaei, France24

Panellists
Izumi Nakamitsu, United Nations Under-Secretary-General and High Representative for Disarmament Affairs
Romain Murenzi, Executive Director, The World Academy of Sciences
Jennifer Thomson, President, Organization for Women in Science for the Developing World

The Forum on Global Citizenship and Youth Inclusion

Moderator
Monika Fröhler, Chief Executive Officer of the Ban Ki-moon Centre for Global Citizens, Austria

Panellists
Heinz Fischer, former President of the Republic of Austria, Ban Ki-moon Centre for Global Citizens, Austria
Bachir Ismaël Ouedraogo, Minister of Energy of Burkina Faso
Keenya Hofmaier, Content Manager for PARIS TALKS, France
Bernd Hermann, Akademisches Forum für Außenpolitik Wien - AFA, Austria
Sahil Shah, Policy Fellow at European Leadership Network, United Kingdom
Sylvia Mishra, Fellow at the Nuclear Threat Initiative, United States of America

Round Table Discussion in Spanish
Aplicaciones Civiles y Científicas y Programas de Capacitación de la OTPCE: Un Bien Global Para La Comunidad Internacional
(*CTBTO Civil and Scientific Applications and Capacity Building Programmes: A Global Good for the International Community*)

Moderator
Jordi Kuhs (Austria), Agencia EFE

Panellists
Ambassador Marcel Fortuna Biato (Brazil), Permanent Representative, Permanent Mission of the Federative Republic of Brazil to the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization
Ambassador Alicia Buenrostro Massieu (Mexico), Permanent Representative, Permanent Mission of the United Mexican States to the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization
Ignacio Cartagena Núñez (Spain), Deputy Director General of Nonproliferation and Disarmament, Ministry of Foreign Affairs and Cooperation
Ambassador Luis Gallegos Chiriboga (Ecuador), Permanent Representative, Permanent Mission of Ecuador to the United Nations in New York
Emma Polanco Melo (Dominican Republic), Rector, Autonomous University of Santo Domingo
José Fidel Santana Núñez (Cuba), Vice-Minister, Ministry of Science, Technology and Environment of Cuba

Round Table Discussion in French
Promotion de l'Entrée en Vigueur du TICE - Perspectives et Initiatives
(*Boosting CTBT Entry Into Force: Perspectives and Initiatives)*

Moderator
Alain Foka, Radio France International

Panellists
Ambassador Maria Assunta Accili Sabbatini (Italy), Permanent Representative,
Permanent Mission of the Republic of Italy to the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization
Ambassador Faouzia Boumazia Mebarki (Algeria), Permanent Representative,
Permanent Mission of Algeria in Vienna and Representative of the Co-President Designated for the Article XIV Conference
Ambassador Roger Albéric Kacou (Côte d'Ivoire), Permanent Representative, Permanent Mission of the Republic of Côte d'Ivoire to the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization, President of the Francophone Ambassadors Group in Vienna
Jacques Krabal, Parliamentary Secretary General, Parliamentary Assembly of the Francophonie, France
Rémi Quirion, Chief Scientist of Quebec, Canada
Ambassador Malik Sarr, Representative of the International Organization of the Francophonie, Regional Office of the Indian Ocean

Women in Science and Technology

Opening Remarks
Lassina Zerbo, CTBTO Executive Secretary

Panellists
Sabah Al Momin, Research Scientist in Biotechnology, Kuwait Institute for Scientific Research, Kuwait
Sanghamitra Bandyopadhyay, Director, Indian Statistical Institute; Professor, Machine Intelligence Unit, India
Joanna Bartley, Principal, Culture and Change, Australian Nuclear Science and Technology Organisation, Australia
Grace Liu, East Asia Nonproliferation Program, James Martin Center for Nonproliferation Studies, United States of America
Alena Yakovleva, President, Women in Nuclear Russia

CTBTO Youth Group: Agents of Change in Peace, Development and Security

Moderator
Elena Sokova, James Martin Center for Nonproliferation Studies

Panellists
Marzhan Nurzhan, convener of the Abolition 2000 Youth Working Group, Coordinator of Parliamentarians for Nuclear Non-proliferation and Disarmament for CIS States, and member of the CTBTO Youth Group
Gaopalelwe Santswere, Executive Chairperson, South African Young Nuclear Professionals Society, South Africa
Tatsujiro Suzuki, Director and Professor at the Research Center for Nuclear Weapons Abolition, Nagasaki University, Japan
Hind Touissate, award winning blogger and founder of BetaChangemakers, a social enterprise in Morocco

Communicating Science

Moderator
François Murphy, Reuters

Panellists
James Gillies, European Laboratory for Particle Physics (CERN), Geneva, Switzerland
Yael Lavie, BLOCKTV, Israel
Karin Orantes, United Nations Department of Public Information, New York

CTBT Innovation Challenge
CTBTO and the 2030 United Nations Agenda for Sustainable Development: Strengthening the Link

Moderator
Angela Kane, Designated Professor, Disaster Mitigation Research Center, Nagoya University, Japan

Panellists
Ambassador Abel Adelakun Ayoko, Under-Secretary of the Directorate of Regions and International Organizations, Nigerian Ministry of Foreign Affairs
Ambassador John Bernhard, Associate, Global Nexus Initiative about Nuclear Energy, Climate Change and Security Ambassador to the International Atomic Energy Agency from Denmark (retired)
Ana María Cetto, Institute of Physics, National Autonomous University of Mexico

Highlight Talks
Knowledge of the Geosphere Structure and Dynamics – Knowledge Gained from 20 Years of the CTBT

Highlight Talk 1

Introduction
Elisabeth Blanc, Research Director at the French Alternative Energies and Atomic Energy Commission, France, ARISE Project (Europe)

Invited Speaker
Michel Jean, Director General of the Canadian Meteorological and Environmental Prediction Centre, Meteorological Service of Canada, Environment and Climate Change Canada, and Chair of the Commission for Basic Systems of the World Meteorological Organization

Highlight Talk 2

Introduction
Alik Ismail-Zadeh, Karlsruhe Institute of Technology, Institute of Applied Geosciences, Karlsruhe, Germany

Invited Speaker
Tarje Nissen-Meyer, Associate Professor of Geophysics, Department of Earth Sciences, University of Oxford, United Kingdom

Highlight Talk 3

Introduction
Yoshiyuki Kaneda, Designated Professor at the Disaster Mitigation Research Center, Nagoya University, Japan

Invited Speaker
Hanne Sagen, Polar Acoustics and Oceanography Group, Nansen Environmental and Remote Sensing Center, Norway

Scientific Applications: Science of Climate Change with CTBT Technologies

Moderator
Tammy Taylor, SnT2019 Project Executive, Director of the International Data Centre Division, CTBTO

Panellists
Rebecca Manzou, Meteorological Services Department, Zimbabwe
Hanne Sagen, Polar Acoustics and Oceanography Group, Nansen Environmental and Remote Sensing Center, Norway
Jean Sciare, Director, Energy, Environment and Water Research Center, The Cyprus Institute, Cyprus
Lucrezia Terzi, Belgian Nuclear Research Centre, Belgium

Science Diplomacy: Science Advisors and Arms Control Practice - Improving Policy Implementation Through Technical Expertise

Moderator
Mahlet Mesfin, American Association for the Advancement of Science Center for Science and Diplomacy, Deputy Director of the Center for Science Diplomacy, United States of America

Panellists
Jonathan Forman, Science Policy Advisor and Secretary to the Scientific Advisory Board of the Organisation for the Prohibition of Chemical Weapons
Peng Li, R. Senior Colonel of Chinese Preparatory Secretariat on CTBT, Director of China Arms Control and Disarmament Association, Senior Advisor of Chinese HOPE Investment and Development Corp., China
Mosa Mabuza, Chief Executive Officer, Council for Geoscience, South Africa
Man-Sung Yim, Director, Korea Advanced Institute of Science and Technology, Republic of Korea

Getting the Non-Proliferation and Disarmament Architecture Back on Track

Moderator
Tariq Rauf, Former Head of Verification and Security Policy, International Atomic Energy Agency

Panellists
Ambassador Alicia Buenrostro Massieu, Permanent Representative, Permanent Mission of the United Mexican States to the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization
Ignacio Cartagena Núñez, Deputy Director General of Nonproliferation and Disarmament, Ministry of Foreign Affairs and Cooperation, Spain
Ambassador Rafael Grossi, Permanent Representative, Permanent Mission of the Argentine Republic to the Vienna-based International Organizations
Ivan Timofeev, Programme Director, Russian International Affairs Council, Russian Federation

Civil Applications: The Use of CTBT IMS Data in Support of Disaster Risk Mitigation

Moderator
Bruce Howe, Research Professor, Department of Ocean and Resources Engineering, School of Ocean and Earth Science and Technology, University of Hawai'i at Mānoa, United States of America

Panellists
Elisabeth Blanc, Research Director, French Alternative Energies and Atomic Energy Commission, France, ARISE Project (Europe)
Laura Kong, Director, International Tsunami Information Centre, United Nations Educational, Scientific and Cultural Organization/Intergovernmental Oceanographic Commission/National Oceanic and Atmospheric Administration, United States of America
Ricardo Mena, Chief, Sendai Framework Monitoring Branch, United Nations Office for Disaster Risk Reduction
Steven Pawson, Chief, Global Modeling and Assimilation Office, National Aeronautics and Space Administration, United States of America

Juan Carlos Villagran, Head of Office, United Nations Platform for Space-Based Information for Disaster Management and Emergency Response

vDEC Briefings: Experience in Using CTBT IMS Data for Scientific Applications

Moderator
Jolanta Kusmierczyk-Michulec, Atmospheric Sciences Officer, CTBTO

Presenters
Rodrigo de Negri, Geophysics Department, University of Chile
So-Gu Kim, Korea Seismological Institute, Republic of Korea
Won-Young Kim, Lamont-Doherty Earth Observatory, Seismology Geology and Tectonophysics Division, Columbia University, United States of America
Wolfango Plastino, Department of Mathematics and Physics, Roma Tre University, Italy
Dirk Metz, Japan Agency for Marine-Earth Science and Technology, Japan
Tracey Rogers, Center for Earthquake and Tsunami Research Japan Agency for Marine-Earth Science and Technology, Japan

DPRK Nuclear Testing – CTBTO Expertise and Knowledge

Moderators
Tammy Taylor, SnT2019 Project Executive, Director of the International Data Centre Division, CTBTO
Anders Ringbom, Research Director**,** Swedish Defence Research Agency (FOI)

Panellists
Jeffrey Lewis, Director, East Asia Nonproliferation Program, James Martin Center for Nonproliferation Studies, United States of America
Paul Richards, Special Research Scientist, Lamont-Doherty Earth Observatory, Seismology Geology and Tectonophysics Division, Columbia University, United States of America
Petra Seibert, Associate Professor, University of Natural Resources and Life Sciences Vienna, Institute of Meteorology, Austria
Vitaly Shchukin, Head of Laboratory of the Theoretical Division at the Russian Federal Nuclear Center - All-Russia Scientific Research Institute of Technical Physics, Russian Federation
Brian Stump, Albritton Professor of Earth Sciences, Dedman College of Humanities and Sciences, Southern Methodist University, United States of America

What Kind of Improvement Can Artificial Intelligence Bring to the Work of the CTBTO?

Moderator
Heidi Kuzma, Chief Technology Officer of BetaZ, United States of America

Panellists
Stuart Russell, Professor of Computer Science and Smith-Zadeh Professor in Engineering, University of California, Berkeley, United States, and Honorary Fellow, Wadham College, Oxford University, United Kingdom
Korhan U. Şemi, Geophysics Engineer, Boğaziçi University, Kandilli Observatory and Earthquake Research Institute, Turkish NDC, Belbaşı Nuclear Tests Monitoring Center, Turkey
Kardi Teknomo, Associate Professor, Department of Information System and Computer Science, Ateneo de Manila University, the Philippines

Where Do You See the IMS Monitoring Technologies Evolving for Enhanced Capability?

Moderator
Nurcan Meral Özel, SnT2019 Project Executive, Director of the International Monitoring System Division, CTBTO

Panellists
Naila Babiker, Assistant Professor, Seismological Research Institute Sudan, Sudan National Data Centre, Sudan
Roberto Betancourt Arocha, President of Venezuelan Foundation for Seismological Research, Venezuela
Valerie Flavin, French Alternative Energies and Atomic Energy Commission, France
Cansun Guralp, Founder, Güralp Systems Limited, United Kingdom
Noriko Kayama, Coordination Center for Prediction Research of Earthquakes and Volcanic Eruptions, Earthquake Research Institute, University of Tokyo, Japan

Fishbowl Discussion: Reducing Uncertainty in Sensor Networks

Moderator
Sergio Barrientos, Director, National Seismological Center of University of Chile, Chilean National Seismic Network, Chile

Civil Applications: Towards Monitoring Near-Earth Objects Impacting the Atmosphere

Introduction
Romana Kofler, Programme Officer at the United Nations Office for Outer Space Affairs and Secretary of the Working Group of the Committee on the Peaceful Uses of Outer Space

Moderator
Detlef Koschny, Head of the Near Earth Objects Team at the European Space Agency

Panellists
Peter Brown, Professor, University of Western Ontario, and Canada Research Chair, Department of Physics and Astronomy, Canada
Esther Drolshagen, Institute of Physics, Department of Medical Physics and Acoustics, Carl von Ossietzky University of Oldenburg, Germany
Gerhard Drolshagen, Institute of Physics, Department of Medical Physics and Acoustics, Carl von Ossietzky University of Oldenburg, Germany
Romana Kofler, Programme Officer at United Nations Office for Outer Space Affairs and Secretary of the Working Group on Committee on the Peaceful Uses of Outer Space, Austria

Threats of Tomorrow: Use of Artificial Intelligence and Machine Learning in Predicting and Responding to Malware

Moderator
Katherine Gagnon, Information Security Chief, United Nations World Food Programme

Panellists
Leesa Carson, Cybersecurity and Cloud Computing, Branch Head, Community Safety, Geoscience Australia, Australia
Timo Mischitz, Information Security Coordinator, Organisation for Security and Co-operation in Europe
Bojan Smetic, UN-centric Shared Intelligence Threat Platforms and Integration with AI, United Nations International Computing Centre
Emily Taylor, Associate Fellow with the International Security Department and Editor of the *Journal of Cyber Policy*, Chief Executive Officer of Oxford Information Labs, Chatham House, The Royal Institute of International Affairs, United Kingdom
Neil Walsh, Chief, Cybercrime and Anti-Money Laundering Section, United Nations Office on Drugs and Crime

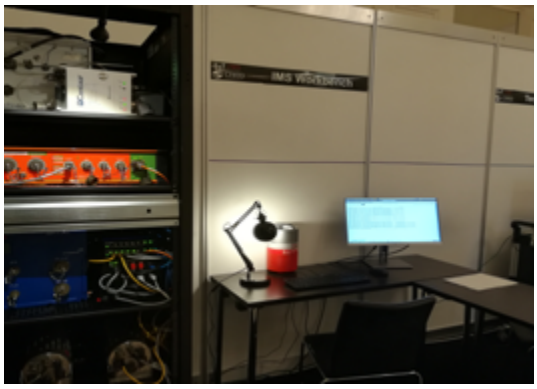
On-Site Inspections Triggered by Events in Complex, Dynamic or Challenging Environments

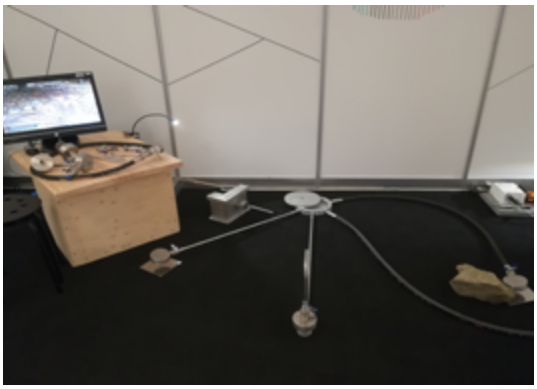
Moderator
John Walker, Head, Arms Control and Disarmament Research Unit, Foreign and Commonwealth Office, United Kingdom

Panellists
Jeff Ashby, Director, Webster Drilling and Exploration Limited, New Zealand
Joel Hirschi, Associate Head of Marine Systems Modelling, National Oceanography Centre, United Kingdom
Vitaly Shchukin, Head of Laboratory, Theoretical Division, Russian Federal Nuclear Center, All-Russia Scientific Research Institute of Technical Physics, Russian Federation
Xiaodong Yang, Chief, Legal Services Section, CTBTO

APPENDIX III

Appendix 3





APPENDIX III

Exhibitions, Demonstrations and Technical Visits

PTS exhibitions, demonstrations and technical visits showcased selected activities and achievements of the organization and also highlighted future scientific and technological needs under the mission of the CTBTO.

Topics Covered by the PTS Poster Exhibition on Goals and Needs

- Operation of the International Monitoring System
- Trends in Waveform Data Processing and Analysis at the International Data Centre
- Analysis of CTBTO Seismic, Hydroacoustic and Infrasound Data from the September 2017 Democratic People's Republic of Korea Nuclear Explosion
- Noise Computation in Seismic, Hydroacoustic and Infrasound Data Processing
- The Sustainment of the IMS Hydroacoustic Network
- Infrasound in and Towards IDC Operations
- Towards Inclusion of Atmospheric Dynamic into Infrasound Processing
- New Filter Material Selection and Testing for IMS Radionuclide Particulate Stations
- Enhancements to the CTBTO IDC Radionuclide Processing Pipeline for Particulate Samples
- Improved Methods for Estimating Possible Source Regions of Radionuclide Releases from Atmospheric Transport Modelling - WEB-GRAPE: Web-Connected Graphics Engine
- Data-Fusion: Tool of Waveform Events and Radionuclide Detections
- Extended NDC in a Box Project
- Services to States Signatories
- Training Cycle Approach for the National Data Centres 1.0 (TCAN 1.0)
- vDEC: Virtual Data Exploitation Centre
- Use of IMS Data and IDC Products to Mitigate the Impact of Natural and Other Catastrophes

Displays of International Monitoring System and On-Site Inspection Equipment

- The display of infrasound and seismic equipment of the IMS included:
    - Equipment rack with the following instruments:
    - Nanometrics Centaur digitizer
    - Nanometrics Europa-T digitizer
    - Kinemetrics Quanterra Q330M+ digitizer
    - CEA/DASE Aubrac digitizer
    - Guralp DM24 digitizer
    - GPS repeater for timing
    - PrioComp computer with SSI software and calibration module
    - PrioSys rack mounted computer with SSI software and calibration module
- Sensors:
    - MB3 and MB2000 microbarometers
    - CMG 3T 1500 seismometer
    - Digital weather station and EMAM authentication console
- Two training trolleys with Europa-T and Guralp DM24 digitizers, PrioComp computers, SSI software and calibration modules
- Elements of wind noise reduction system, including stainless steel pipes, flexible rubber hoses, summing manifold, inlet ports and example of stainless steal equipment vault
- Screen with video presentations of installation and elements of IMS infrasound stations
    - Network equipment

IMS radionuclide station equipment including the detectors and their electronics:

- Radionuclide station components:
  - Hyper-pure germanium (HPGe) crystal
  - Ortec gamma detector and DSPec50
  - Canberra gamma detector and LYNX
  - BSI monolith gamma detector (under validation)
  - Station communication infrastructure
  - Weather station and sample barcode system
  - Sample filters and sample preparation tools

- Laptop with live presentation on daily work of station operator and station specific software used at radionuclide stations
- A continuous loop of photographs and video footage from IMS radionuclide station installation and maintenance activities
- Two posters, on radionuclide station layout and on technology foresight on detection system

The On-Site Inspection display had three main parts:

- Equipment for OSI
- Equipment for the intermodal rapid deployment system
- Other OSI tools that support the conduct of an OSI, such as the Geospatial Information System for OSI (GIMO), health and safety equipment and Quality Management System documentation

The static and interactive displays of OSI equipment included:

- Position finding equipment
- Ground-based visual observation equipment
- Gamma radiation monitoring backpack
- Noble gas sub-soil gas sampling unit
- Air sampling units were available to SnT participants
- Intermodal rapid deployment container for surface and air transport

Interactive demonstrations included:

- Asset tracking (Radio-frequency identification fixed readers, portable scanners, database/monitor)
- Geospatial Information Management for OSI (GIMO) system

Short videos on OSI and PTS activities framed the exhibition throughout the conference.

Additional Exhibitions

- CTBTO Human Resources Services
  - Booth with brochures, videos and staff available for questions
  - Interactive sessions "Attracting Talent to Put an End to Nuclear Testing: Working in CTBTO"
- Visual and artistic displays including equipment, videos and short presentations
- Art Meets Science: Youth Art Competition
- Race for Ratification
- Interactive Exhibits: OmniGlobe
- Carrera Race Track
- United Nations Sustainable Development Goals (SDGs) Challenge Posters

PTS Scientific and Operational Demonstrations

Demonstrations by PTS staff of scientific and operational activities and software included:

- Waveform Analysis
- Radionuclide Analysis
- CTBTO Event Portal
- IDC FAST (waveform fingerprinting)
- NDC in a Box Radionuclide software

- NET-VISA software
- Radionuclide spectra classification with neural network
- TimescaleDB for raw waveform data
- WEB-GRAPE Internet Based Service

Technical Visits to the CTBTO Technology Support and Training (TeST) Centre

The newly built Technology Support and Training (TeST) Centre of the CTBTO in Seibersdorf, Austria, provides the CTBTO with infrastructure and required space for storage, maintenance, testing and training. While it serves to a large extent as an equipment storage and maintenance facility, including for the requirements of the On-Site Inspection Division, it also benefits the CTBTO as a whole with state of the art workshop and training facilities. As such, it will contribute to further development of the monitoring and verification system of the Treaty, making the work of the CTBTO even more visible and attesting to the fact that it is already capable of operating according to its mandate. SnT participants were offered the opportunity to visit the new facility to experience first-hand this milestone in the history of the CTBTO.

Appendix 4

Scientific Programme Committee

TIM AHERN (USA)
Director of Data Services
Incorporated Research Institutions for Seismology (IRIS)

ATALAY AYELE (Ethiopia)
Associate Professor, Director
Institute of Geophysics, Space Science and Astronomy (IGSSA)

ELISABETH BLANC (France)
Research Director
French Alternative Energies and Atomic Energy Commission (CEA)

ARISTIDE ALY BOYARM (Burkina Faso)
Co-Founder, Managing Director
Africa CRM&SI

LI HUA (China)
Professor, Chairman of the Science and Technology Committee
Chinese Academy of Engineering Physics (CAEP)

ALIK ISMAIL-ZADEH (Germany–Russian Federation)
Senior Scientist
Institute of Applied Geosciences, Karlsruhe Institute of Technology
Secretary General of the International Union of Geodesy and Geophysics

GIHAN KAMEL (Jordan)
Infrared Beamline Scientist
Synchrotron-Light for Experimental Science and Applications in the Middle East (SESAME)

YOSHIYUKI KANEDA (Japan)
Designated Professor, Executive Advisor of the President of Kagawa University
Vice Director, Institute of Education, Research and Regional Cooperation for Crisis Management Shikoku (IECMS), Kagawa University

ALEXEY A. MALOVICHKO (Russian Federation)
Scientific Leader
Geophysical Survey of the Russian Academy of Sciences (RAS)

MAHLET N. MESFIN (USA)
Deputy Director
Center for Science Diplomacy, American Association for the Advancement of Science (AAAS)

AL-SHARIF NASSER BIN NASSER (Jordan)
Managing Director
Middle East Scientific Institute for Security

JEAN-PAUL NGOME ABIAGA (France)
Assistant Programme Specialist
International Basic Sciences Programme
United Nations Education, Scientific and Cultural Organization (UNESCO)

MOBOLAJI OLADOYIN ODUBANJO (Nigeria)
Executive Secretary
Nigerian Academy of Science

PAUL GRANSTON RICHARDS (USA)
Special Research Scientist and Professor Emeritus of Natural Sciences
Lamont-Doherty Earth Observatory, Columbia University

ANDERS RINGBOM (Sweden)
Research Director
Swedish Defence Research Agency (FOI)

EUGENIO POLANCO RIVERA (Dominican Republic)
Seismology Researcher and Director
National Seismology Center
Autonomous University of Santo Domingo (UASD)

RICARDO SAGARZAZU (Argentina)
Vice President for Strategic Development
INVAP

FRANCOIS SCHINDELE (France)
Expert, Seismology and Tsunami Warning
French Alternative Energies and Atomic Energy Commission (CEA)

JEAN SCIARE (Cyprus)
Director
Energy, Environment and Water Research Center
The Cyprus Institute

GLENN E. SJODEN (USA)
Chief Scientist
Air Force Technical Applications Center (AFTAC)

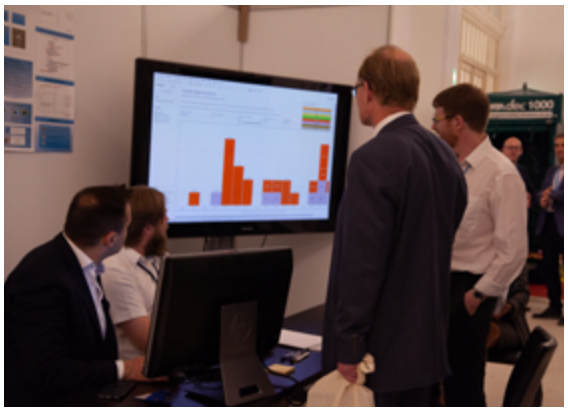
ZEINABOU MINDAOUDOU SOULEY (Niger)
Special Advisor to the President of the Republic of Niger
Chair of the High Authority for Atomic Energy of Niger
Vice-Chairperson of Working Group B

CHRISTOPHER TIMPERLEY (United Kingdom)
Chair of Scientific Advisory Board
Technical Fellow for Chemistry, Defence Science and Technology Laboratory
Organisation for the Prohibition of Chemical Weapons (OPCW)

JOHN R. WALKER (United Kingdom)
Head, Arms Control and Disarmament Research Unit
Foreign and Commonwealth Office

MAN-SUNG YIM (Republic of Korea)
Professor, Department of Nuclear and Quantum Engineering
Dean, Khalifa University of Science and Technology–Korea Advanced Institute of Science and Technology (KUSTAR-KAIST)
Director, Nuclear Nonproliferation Education and Research Center at KAIST

JOHN ZUCCA (USA)
Physicist and Deputy for Programmes for the Global Security Directorate
Lawrence Livermore National Laboratory (LLNL)



APPENDIX V

Appendix 5

Exhibitors and Sponsors

EXHIBITORS

ATOMTEX SPE
Baltic Scientific Instruments
Canberra Packard
Cegelec Défense
Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France
F&J Specialty Products, Inc.
Gempa GmbH
General Dynamics Mission Systems
Guideline Geo
Güralp Systems Ltd.
HOPE Investment and Development Corp. Ltd., China
Hughes Network Systems LLC
Instrumental Software Technologies, Inc. (ISTI)
International Seismological Centre (ISC)
Kinemetrics, Inc.
Leica Geosystems Austria GmbH
Lennartz Electronic Sonicona
MEET Instruments GmbH
National Physical Laboratory
ORTEC AMETEK
Raspberry Shake
Scienta Sensor Systems AB
Seismo Wave
Teledyne Brown Engineering, Inc.
Tracerco
Trimble Inc.

SPONSORS

ATOMTEX SPE
Baltic Scientific Instruments, SIA
European Union Delegation
F&J Specialty Products, Inc.
Guideline Geo
Instrumental Software Technologies, Inc. (ISTI)
Kinemetrics, Inc.
MEET Instruments GmbH
Nanometrics
Norwegian Seismic Array (NORSAR)
ORTEC AMETEK
Scienta Sensor Systems AB

Appendix 6

Statistics

The fifth CTBT: Science and Technology conference did not only include outstanding presentations and remarkable new findings in various scientific fields. It also marked a number of major milestones in terms of overall participation and especially in increasing the number of women attending and sharing their expertise at the conference.

Word cloud based on all technical terms occurring in the abstracts of SnT2019 presentations.

Data collected over the course of the last three SnT conferences are presented below and provide thorough statistical insight into some of the most essential conference details.

Number of Participants

The number of participants in SnT conferences has steadily increased, with 1200 participants in 2019. Table 6.1 provides an overview of the number of participants and gender distribution since SnT2015.

Table 6.1. Participation in Science and Technology Conferences (2015, 2017, 2019)

Year	Men	Women	Total
SnT2015	518	182	700
SnT2017	621	279	900
SnT2019	617	583	1200

Regional Distribution of Participants

Table 6.2 presents an overview of the regional distribution of participants at the SnT2019 conference.

Table 6.2. Regional Distribution of Participants at SnT2019

Region	(%) Share
Africa	6.6%
Eastern Europe	8.4%
Latin America and the Caribbean	3.5%
Middle East and South Asia	5.7%
North America and Western Europe	57.1%
South East Asia, the Pacific and the Far East	5.6%
International Organizations	13.0%

Downloads of SnT2019 Mobile App

The SnT2019 Mobile App was accessible to all conference attendees on their digital devices and offered many useful functions that facilitated an even more exciting conference experience. The popularity of the mobile application was clearly reflected in the exponential increase in the number of downloads during the SnT2019 in comparison with SnT2017, when the application was initially launched. Table 6.3 presents an overview of app downloads at SnT2017 and SnT2019.

Table 6.3. Downloads of SnT Mobile App

Year	Number of Downloads
SnT2017	387
SnT2019	938

Panel Discussions

Group discussions are one of the most interesting ways to exchange knowledge and encourage lively debate. The CTBT: Science and Technology conference series has always served as a platform for people from all over the world to share new findings and converse about future developments. The number of panel discussions at SnT2019 was more than double the number of past conferences. Table 6.4 presents an overview of panel discussions at SnT2015, SnT2017 and SnT2019.

Table 6.4. Number of Panel Discussions at SnT Conferences (2015, 2017, 2019)

Year	Number of Panel Discussions
SnT2015	7
SnT2017	9
SnT2019	19

Distribution of Panellists by Geographical Region and Gender

The panellists at SnT2019 were as geographically diverse as the participants in the conference. Table 6.5 shows the distribution of panellists according to geographical region and gender.

Table 6.5. Distribution of SnT2019 Panellists by Geographical Region and Gender

Geographical Region	Women	Men	Total	(%) Share
Africa	3	6	9	9%
Eastern Europe	2	5	7	7%
Latin America and the Caribbean	4	7	11	11%
Middle East and South Asia	5	0	5	5%
North America and Western Europe	16	27	43	44%
South East Asia, the Pacific and the Far East	4	7	11	11%
International Organizations	4	8	12	12%
Total	38	60	98	100%

Oral Presentations

At the heart of this prestigious event were the individual presentations under each of the themes. The number of oral presentations has steadily increased, which clearly indicates the popularity of the SnT conference series. Table 6.6 presents an overview of the number of oral presentations at SnT2015, SnT2017 and SnT2019.

Table 6.6. Number of Oral Presentations at SnT Conferences (2015, 2017, 2019)

Year	Oral Presentations
SnT2015	80
SnT2017	100
SnT2019	118

Poster Presentations

Posters are a visual representation of different themes and topics. Table 6.7 presents an overview of the number of poster presentations at SnT2015, SnT2017 and SnT2019.

Table 6.7. Number of Poster Presentations at SnT Conferences (2015, 2017, 2019)

Year	Poster Presentations
SnT2015	320
SnT2017	340
SnT2019	342

Table 6.8 presents an overview of SnT2019 oral and poster presentations according to theme and topic.

Table 6.8. SnT2019 Presentations According to Theme and Topic

Theme and Topic	Oral Presentations	Poster Presentations
Theme 1. The Earth as a Complex System	28	57
T1.1 Atmospheric Dynamics	11	20
T1.2 Solid Earth Structure	5	26
T1.3 Properties of the Ocean	9	5
T1.4 Interaction Among the Earth's Subsystems	3	6
Theme 2. Events and Nuclear Test Sites	31	96
T2.1 Characterization of Treaty-Relevant Events	7	27
T2.2 Challenges of On-Site Inspection	8	4
T2.3 Seismoacoustic Sources in Theory and Practice	3	19
T2.4 Atmospheric and Subsurface Radionuclide Background and Dispersion	10	38
T2.5 Historical Data from Nuclear Test Monitoring	3	8
Theme 3. Verification Technologies and Technique Application	29	113
T3.1 Design of Sensor Systems and Advanced Sensor Technologies	10	37
T3.2 Laboratories Including Mobile and Field Based Facilities	3	6
T3.3 Remote Sensing, Satellite Imagery and Data Acquisition Platforms	2	6
T3.4 Augmented Reality and Fusion of Data from Different Monitoring Technologies	1	3
T3.5 Data Analysis Algorithms, Artificial Intelligence, Big Data and Deep Learning	13	61
Theme 4. Performance Optimization	9	32
T4.1 Network Optimization	3	17
T4.2 Systems Engineering	3	0
T4.3 Enabling Technologies	0	5
T4.4 Performance of the Full Verification System	3	10
Theme 5. CTBT in a Global Context	21	44
T5.1 Science in Policy Discussions and Lessons Learned from Other Arms Control Agreements and Arrangements	3	4
T5.2 Experience with and Possible Additional Contributions to Issues of Global Concern such as Disaster Risk Mitigation, Climate Change Studies and Sustainable Development Goals	10	12
T5.3 Capacity Building, Education and Public Awareness	8	28
Total	**118**	**342**

Vendors and Exhibitors

CTBT: Science and Technology is and has always been a diverse conference that offers a great platform to showcase a variety of innovative inventions. Vendors and exhibitors from all across the globe can be found at every SnT presenting new products and technologies. Their number has steadily increased with each successive conference, as shown in Table 6.9.

Table 6.9. Vendors and Exhibitors at SnT Conferences (2015, 2017, 2019)

Year	Number
SnT2015	11
SnT2017	21
SnT2019	26

Appendix 7

Network Visualizations of Countries and Institutions

More details about the clusters in Figure 38: Network Visualization by Country based on the Book of Abstracts (699 abstracts, 56 clusters, 108 countries; CTBTO, IAEA and World Bank were represented independently). CTBTO Library developed this figure using Mendeley and VOSviewer Software.

Countries	Cluster
Armenia	1
Azerbaijan	
Canada	
Georgia	
Hungary	
Iraq	
Jordan	
Oman	
Saudi Arabia	
Cameroon	2
Egypt	
Ghana	
Kenya	
Madagascar	
Nigeria	
South Africa	
Tunisia	
Australia	3
Belgium	
Israel	
Mongolia	
Pakistan	
Republic of Korea (the)	
Russian Federation (the)	
Burkina Faso	4
Central African Republic (the)	
Côte d›Ivoire	
CTBTO	
Ecuador	
Afghanistan	5
Bolivia (Plurinational State of)	
France	
Germany	
Singapore	
Austria	6
Croatia	
Czech Republic (the)	
Romania	
Turkey	

Ethiopia	7
IAEA	
Japan	
United Kingdom of Great Britain and Northern Ireland (the)	
Denmark	8
Namibia	
Netherlands (the)	
Norway	
Bulgaria	9
Italy	
Portugal	
Iran (Islamic Republic of)	10
New Zealand	
Sweden	
Kazakhstan	11
Kyrgyzstan	
Tajikistan	
Chile	12
Malawi	
United States of America (the)	
India	13
Nepal	
World Bank	
China	14
Indonesia	
Botswana	15
Eritrea	
Brazil	16
Switzerland	
Algeria	17
Argentina	18
Bangladesh	19
Belarus	20
Venezuela (Bolivarian Republic of)	21
Colombia	22
Comoros (the)	23
Costa Rica	24
Democratic Republic of the Congo (the)	25
Eswatini	26
Finland	27

Guinea-Bissau	28
Kuwait	29
Latvia	30
Lithuania	31
Malaysia	32
Mexico	33
Morocco	34
Mozambique	35
Myanmar	36
Niger (the)	37
Paraguay	38
Philippines (the)	39
Republic of Moldova (the)	40
Samoa	41
Senegal	42
Slovakia	43
Sri Lanka	44
Sudan (the)	45
Suriname	46
Thailand	47
Turkmenistan	48
Uganda	49
Ukraine	50
United Republic of Tanzania (the)	51
Uzbekistan	52
Viet Nam	53
Zambia	54
Zimbabwe	55
Spain	56

More details about the clusters in Figure 39 Network Visualization by Institutions based on the Book of Abstracts (699 abstracts, 453 institutions, 212 clusters). CTBTO Library developed this figure using Mendeley and VOSviewer Software.

Institutions	Cluster
Bandung Institute of Technology	1
Banjarnegara Geophysical Station of Central Java	
BMKG - Indonesian Agency for Meteorology, Climatology and Geophysics	
EOS - Earth Observatory of Singapore	
Geologi Engineering	
Hasanuddin University	
Indonesian State College of Metetorology Climatolo	
Marine Geological Research and Development Center	
Meterological and Geophysical Agency	
National Central University of Taiwan	
Physics Department of Syiah Kuala University	
STMKG - State College of Meteorology Climatology and Geophysics	
Syiah Kuala University	
TDMRC - Tsunami and Disaster Mitigation Research Center	
UNESA - State University of Surabaya	
University of Syiah Kuala	

AFTAC - Air Force Technical Applications Center	2
ARSN - Autorité Sénégalaise de Radioprotection et de Sûreté Nucléaire	
CNRS - Centre National de la Recherche Scientifique	
Geoscience Australia	
IRD - GEOAZUR	
Japan Weather Association	
Kegman Inc	
MCTPEN - Ministère de la Communication, des Télécommunications, des Postes et de l'Economie numérique	
MESRI - Ministere de l'Enseignement Supérieur, de la Recherche et de l'Innovation	
Mongolian Academy of Sciences	
National University of Mongolia	
UCAD - Université Cheikh Anta Diop	
Université de Thiés	
US Department of State	
Astronomy and Earth Sciences	3
Azerbaijan National Academy of Sciences	
Gempa GmbH	
Ilia State University	
Institut de Phsysique du Globe de Paris	
Lawrence Livermore National Laboratory	
MTA Research Centre for Astronomy and Earth Sciences	
National Academy of Sciences of Armenia	
Onur Seemann Consulting Inc	
Saudi Geological Survey	
Sultan Qaboos University	
University of Arkansas at Little Rock	
University of Basra	
University of Milan-Bicocca	
CTBTO - Comprehensive Nuclear-Test-Ban Treaty Organization	4
Instituto Geofisico	
International Institute for Applied Systems Analysis	
JAEA - Japan Atomic Energy Agency	
NAIK Institute of Agricultural Engineering	
National Data Centre of Bangui	
National Defense University	
Station Geophysique de Lamto	
Tbilisi State University	
Tokyo Institute of Technology	
University of British Columbia	
Zuehlke Engineering	

APPENDIX VII

APPENDIX VII

AWE Aldermaston	5
Federal Office for Radiation Protection (BfS)	
Health Canada	
Hitachi	
Hitachi-GE Nuclear Energy	
IAEA - International Atomic Energy Agency	
Leibniz University	
National Physical Laboratory	
Radiation Protection Bureau	
Royal Meteorological Institute of Belgium	
SCK CEN - Belgian Nuclear Research Center	
University of Surrey	
BGR - Federal Institute for Geosciences and Natural Resources	6
CNRM - Centre National de Recherches Météorologiques	
DLR - German Aerospace Center	
Earth Observatory of Singapore	
IFREMER - Institut Français de Recherche pour l'Exploitation de la Mer	
LATMOS	
Leibniz Institute of Atmospheric Physics	
Meteorological Institute Munich	
NTNU - Norwegian University of Science and Technology	
Observatoire de Paris	
TU Munich	
University of Oldenburg	
CTBTO Young Professionals Network	7
Delft University of Technology	
Geological Survey of Namibia	
Harman Karden	
KNMI - Royal Netherlands Meteorological Institute	
National Center for Physical Acoustics	
National Nuclear Security Administration	
NORSAR	
Southern Methodist University	
TU Delft	
University of Mississippi	
Cairo University	8
Center for Surveying	
CNS - James Martin Center for Nonproliferation Studies	
CNT - Istituto Nazionale di Geofisica e Vulcanologia	
EAEA - Egyptian Atomic Energy Authority	
Mansoura University	
MIT	
National Surveying of South Africa	
NRIAG	
University of Geneva	

Afgan Atomic Energy High Commision	9
BOKU	
Dokuz Eylul University	
GFZ - German Research Centre for Geosciences	
Karlsruhe Institute of Technology	
University of Illinois	
University of Innsbruck	
University of Rijeka	
University of Strasbourg	
University of Vienna	
Armenian Association of Seismology and Physics of the Earth's Interior	10
Armenian Regional Survey for Seismic Protection	
CEA - Commissariat à l'Energie Atomique et aux Energies Alternatives	
Centre de Mathématiques et Leurs Applications	
CSIC-UCM	
École Normale Supérieure	
LIMSI - Laboratoire d'Informatique pour la Mécanique et les Sciences de l'Ingénieur	
LMD - Laboratoire de Météorologie Dynamique	
SEISMO WAVE	
Barva Innovation Center	11
Earthquake Engineering and Seismology Methodologic	
Institute of Geology	
Institute of Geophysical Research	
Kazakhstan National Data Centre	
Michigan State University	
National Academy of Sciences of Kyrgyzstan	
Russian Academy of Sciences	
Seismological Experimental	
Canadian Data Centre	12
ENSCO Inc.	
Lawrence Livermore National Laboratory	
Los Alamos National Laboratory	
Nevada National Security Site	
Sandia National Laboratories	
University of Alaska	
University of Lausanne	
US Geological Survey	
ACES - Stockholm University	13
FOI - Swedish Defence Research Agency	
Forsmarks Kraftgrupp	
Georgia Institute of Technology	
Idaho National Laboratory	
Institute of Environmental Science and Research	
Iran Nuclear Regulatory Authority	
Scientia Sensor Systems	

APPENDIX VII

APPENDIX VII

Centre for Geodesy and Geodynamics	14
Council for Geoscience	
Geological Survey Agency	
Ghana Atomic Energy Commission	
Namibian Geological Survey Agency	
University of Benin	
University of Ghana	
University of Portharcout	
Ben-Gurion University of the Negev	15
Geotech Consultant Co.	
Hanyang University	
KAERI - Korea Atomic Energy Research Institute	
KIGAM - Korea Institute of Geoscience and Mineral Resources	
Korea Seismological Institute	
University of Seoul	
Bogazici University	16
Centre for Astronomy and Earth Sciences	
INGV - Istituto Nazionale di Geofisica e Vulcanologia	
Institute of Atmospheric Physics	
NIEP - National Institute for Earth Physics	
UK Met Officer	
ZAMG - Zentral Institution for Meteorology and Geodynamics	
IOGA - Institute and Observatory of Geophysics of Antananarivo	17
IPGP - Institut de Physique du Globe de Paris	
Iraqi National Monitoring Authority	
Jomo Kenyatta University of Agriculture and Techno	
Jordan Seismological Observatory	
National Seismological Center	
University of Nairobi	
AWE Blacknest	18
Bayesian Logic Inc.	
UNCTAD - United Nations Conference on Trade and Development	
University of California	
University of Chile	
University of Oxford	
US Department of Energy	
ANSTO - Australian Nuclear Science and Technology	19
Creare LLC	
IRE - Institute of Radioelements	
ISTI - 1 Instrumental Software Technologies, Inc	
Pacific Northwest National Laboratory	
Carleton University	20
Geology and Geophysics Institute	
GSC - Geological Survey of Canada	
National Research Council	
University of Michigan	
IVAR - Instituto de Investigação em Vulcanologia e Avaliação de Riscos	21
University of Firenze	
University of Reading	
VAAC - Meteo France	

Comenius University Bratislava	22
Earth Science Institute	
Nuclear Regulatory Authority of the Slovak Republic	
Slovak Academy of Sciences	
Botswana Geoscience Institute	23
Botswana International University of Science and Technology	
Eritrea Institute of Technology	
University of Botswana	
China Earthquake Administration	24
Institute of Geophysics	
Seismological Observatory	
Seismology Center	
CNRST - Centre National pour la Recherche Scientifique et Technique	
Mohamed V University at Souissi	25
Université PHB	
University of Ouagadougou	
Japan Agency for Marine-Earth Science and Technology	26
Kagawa University	
National Research Institution for Earth Science and Disaster Resilience	
NIED - National Research Institute for Earth Science and Disaster Resiience	
BfS - Federal Office for Radiation Protection	27
Japan Atomic Energy Agency	
University of Bern	
University of Hamburg	
Astrophysique et Géophysique	28
Centre de Recherche en Astronomie	
CNRAGP - Centre National de Recherche Appliquée en Génie Parasismique	
Université des Sciences et de la Technologie Houari Boumediene	
Geodesy and Geography	29
National Institute in Geophysics	
University of National and World Economy	
Geological Survey of Malawi	30
Malawi University of Science and Technology	
Oklahoma State University	
National Center for Research	31
Nigeria Atomic Energy Commission	
University of Ibadan	
ENEA - Energy and Sustainable Economic Development	32
Sofia University «St. Kliment Ohridski»	
University of Bologna	
Afeka Tel Aviv Academic College of Engineering	33
Soreq Nuclear Research Center	
Tel Aviv University	
ECT - Escola de Ciências e Tecnologia	34
Université de Strasbourg	
University of Science and Technology	
Amir-Kabir University of Technology	35
Atmospheric Science and Meteorological Research Center	
ARL - NOAA/OAR/Air Resources Laboratory	36
University of Maryland	

APPENDIX VII

APPENDIX VII

Arnold Scientific Consulting	37
Boreal Scientific Computing	
Defense Threat Reduction Agency	38
Leidos	
Geological Survey of Denmark and Greenland	39
University of Bergen	
Geology and Volcanic Research Antenna	40
HTTTC - University of Buea	
CODDAE - Collectif pour la défense du Droit à l'Energie	41
HANEA - Haute Autorité Nigérienne à l›Energie Atomique	
European Leadership Network	42
Hudson Institute	
Institute of Information Theory and Automation	43
National Radiation Protection Institute	
IPCS - Institute of Peace and Conflict Studies	44
World-Bank	
Center for International Strategic Studies	45
Islamabad Policy Research Institute	
Konkuk University	46
UST - Korea Institute of Civil Engineering and Building Technologies	
KIT Valley Co. Ltd.	47
Korea Meteorological Administration	
Misr-American College	48
Royal Military College of Canada	
BATAN - Indonesian National Nuclear Energy Agency	49
Nanyang Technological University	
National Research Nuclear University MEPhI	50
Saint Petersburg State University	
Observatorio San Calixto	51
UMSA - Universidad Mayor de San Andrés	
PAGASA - Philippine Atmospheric, Geophysical, and Astronomical Services Administration	52
PNRI - Philippine Nuclear Research Institute	
Ferdowsi University of Mashhad	53
Shahid Beheshti University of Tehran	
SNRRA - 1Sudanese Nuclear & Radiological Regulatory Authority	54
Sudan National Data Center	
Sonicona	55
University of Stuttgart	
National Nuclear Security Support Center	56
Technical University of Moldova	
Georgetown University Law School	57
Trade Promotion Office of Peru to the Russian Federation	
Indian Institute of Technology	58
Tribhuvan University	
TAEC - Tanzania Atomic Energy Commission	59
University of Dar es Salaam	
IGSSA - Institute of Geophysics, Space Science and Astronomy of Addis Ababa University	60
University of Southampton	

APPENDIX VII

University of Brasilia	61
University of São Paulo	
Parsian Seismograph Company	62
University of Tehran	
Columbia University	63
University of Texas	
School of Geosciences	64
University of the Witwatersrand	
University of Douala	65
University of Yaounde I	
IRIS - Incorporated Research Institutions for Seismology	66
USCD - University of California San Diego	
National Centre for Physics	67
Yonsei University South Korea	
Abolition 2000 Youth Network	68
Academy of Science	69
Acoustical Engineering Society of Iran	70
All-Russia Research Institute of Automatics	71
ARN - Autoridad Regulatoria Nuclear	72
ATOMTEX SPE	73
Bangladesh Meteorological Department	74
BSMR Maritime University	75
CBRN Defense Institute	76
Center for Physical Sciences and Technology	77
Centre National pour la Recherche Scientifique et Technique	78
Chilean Nuclear Energy Commission	79
China Seismology Bureau	80
CNDRS - Centre National de Documentation et de Recherche Scientifique	81
CNEA - Comisión Nacional de Energía Atómica de Argentina	82
Colombian Geological Survey	83
Costa Rica Institute of Technology	84
CTBT Beijing National Data Centre and Beijing Radionuclide Laboratory	85
Cumhuriyet University	86
Department of Ecology and Environment in Guangdong	87
Department of Mines and Geology	88
Department of Trade and Industry	89
Ecole Militaire Polytechnique	90
Enviroearth	91
Escuela Superior Politécnica de Chimborazo	92
Eurasian Research Institute	93
Exp Momentum Nigeria Limited	94
FAPHI - Fesenkov Astrophysical Institute	95
Federation of American Scientists	96
FUNVISIS - Fundacion Venezolana de Investigaciones Sismologicas	97
Gaiacode Ltd	98
General Dynamics Mission Systems	99
Geological Institute "Strashimir Dimitrov"	100
Geological Survey and Mines Department	101
Geological Survey of Zambia	102
Geophysical Institute of Israel	103
George Washington University	104

University of Waterloo	207
University of Western Ontario	208
Université Ibn Zohr	209
Ural Federal University	210
VARANSAC - Vietnam Agency for Radiation and Nuclear Safety	211
VNIIA - All-Russia Research Institute of Automatics named after N.L. Dukhov	212

INDEX OF CONTRIBUTING AUTHORS AND PANEL DISCUSSION PARTICIPANTS

All authors and co-authors are included in the following list.

C

D

E

F

G

INDEX

H

I

J

K

L

M

INDEX

N

O

P

INDEX

Q

R

S

T

U

V

W

X

Y

Z