# CTBT: Science and Technology Conference 2025 - SnT2025

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# Book of Abstracts

# Contents


CP Closing Plenary . . . 1
EU EU - CTBTO Partnership . . . 1
HLP High-Level Plenary . . . 1
Ke01 Quantum Sensing & Metrology: The next frontier . . . 2
Ke02 2nd Quantum Revolution: New Gateway to Information Technologies . . . 3
Ke03 ATM in support of radionuclide monitoring: an overview of operational capacities . . . 3
Ke04 Recent highlights of Numerical Weather Prediction and atmospheric composition forecasts at ECMWF: the role of observations . . . 4
Ke05 Machine learning, deep learning and high-performance computing . . . 4
Ke06 Bridging Worlds, Building Futures: The Evolving Role of National Data Centres 4
Ke07 Sustainment of the International Monitoring System: The Value Beyond the Strategy . . . 5
Ke08 The GSE story: Conceptual development of the CTBT verification system . . . 5
Ke09 Broadening the Impact of OSI Exercises and Field Tests . . . 6
Ke10 Supershear rupture and its interpretation for the 2025 Mw7.7 Mandalay, Myanmar Earthquake . . . 6
Ke11 The Kamchatka Earthquake of 2025, M8.8: Results from Regional Data Processing . . . 7
Ke12 AI in Medicine: Data, Models, Trust, and Global Preparedness . . . 7
O1.1-133 Model of atmospheric gravity wave perturbations and their effect on localization of infrasound field and its sources . . . 8
O1.1-143 Studying the correlation between wind noise levels and topography for wind noise mapping and site selection . . . 8
O1.1-155 Observation of fireworks to understand the nonlinear behavior of shock waves excited by explosions . . . 9
O1.1-324 Towards a tool to assess and update atmospheric specifications in the middle atmosphere using microbarom observations . . . 9
O1.1-579 Tracking jetstream winds through gravity waves arriving on surface based pressure sensors . . . 10
O1.2-209 A data driven, grid refinement approach to improve global scale regional seismic travel time prediction . . . 11
O1.2-305 Seismicity and Stress Field Changes in the Afar and its surroundings . . . 11
O1.2-349 Seismic Activity in Madagascar: Study of the Origins of Moderate Magnitude Earthquakes . . . 12
O1.2-510 Image Earth's Inner Core Fine-scale Heterogeneity and Temporal Changes using IMS arrays . . . 13
O1.2-535 The crustal thickness and Vp/Vs ratio in Mongolia . . . 13
O1.2-736 Enhancing Earthquake Monitoring in Namibia with an integration of IMS Stations . . . 14
O1.3-172 T-phases Recorded by the IMS Hydrophone Network from Tsunamigenic Earthquakes in Indonesia . . . 14

O1.3-278 The CTBT IMS: a window into a century of global soundscapes (1920-2020) 15
O1.3-299 A Portable Experimental Buoy for Coastal Acoustic Monitoring as a Potential Complement to the IMS Hydroacoustic Network: Applications on the Argentinian Continental Shelf . . . 15
O1.3-787 Trends in shipping sound for all European seas from 2016 to 2050 . . . 16
O2.1-235 Comparison of Inversion Methods for Calculating Full Moment Tensor Solutions using Earthquake and Announced Nuclear Test Datasets . . . 17
O2.1-309 Nuclear event source type characterization with three-dimensional spatial analysis of radioxenon isotopic activity ratios . . . 17
O2.1-453 Limits of explosion discrimination for monitoring efforts with machine learning . . . 18
O2.1-677 Status of radionuclide source location exercise for the automatic data fusion tool at the CTBTO . . . 19
O2.1-752 Dynamic Graph Neural Networks for Spatio-Temporal Seismic Event Localization and Characterization with Multimodal Integration . . . 19
O2.2-116 Automatic Detection of Seismic and Infrasonic Signals from Nuclear Explosions Based on Machine Vision . . . 20
O2.2-216 Seismic and acoustic signals from the 2014 'Interstellar Meteor' . . . 20
O2.2-250 Advances in Seismoacoustic Science and Technology Based on Long-Term Network Operations . . . 21
O2.2-410 Using Distributed Acoustic Sensing to observe seismicity from underground chemical explosions . . . 22
O2.2-767 Analysis of Infrasound signals generated by a Bolide on July 28, 2022 . . . 22
O2.3-219 New insights into isotopic activity ratios of discharges from nuclear facilities . . . 23
O2.3-247 Selecting the Right Noble Gas Tracer: Balancing Experiment Needs and Practical Challenges . . . 23
O2.3-272 First results of radioxenon detections of SAUNA III and three SAUNA QB networks in Lithuania . . . 24
O2.3-436 Subsurface to atmospheric transport of radionuclides using physics-based and machine learning models . . . 25
O2.3-704 Molten Salt Reactor (MSR) Off-Gas System Efficiency and Its Possible Impact on Radioxenon Release Trajectory Estimations . . . 25
O2.3-715 Impact of Nuisance Background on Source Location Models . . . 26
O2.4-437 Present and Future of Seismic Patrimony Preservation Tutorial . . . 26
O2.4-656 New NMSOP chapter on analog seismogram processing . . . 27
O2.4-667 Induced seismicity in the area of nuclear test sites . . . 27
O2.4-879 Sustainable preservation of analogue seismic data in Germany – Digitization test and reference event source parameters . . . 28
O3.1-256 Pisces updates for integrating CSS3.0-like database tables and files into ObsPy workflows . . . 29
O3.1-361 Infrasound uncertainty propagation: ensuring traceability from the laboratory to the field . . . 29
O3.1-722 A strategy for the development of metrology to enhance the sustainment of the seismic and infrasound component of the IMS network . . . 30
O3.1-761 Exploring the Potential of a Barometer as a Transfer Standard for Infrasound Calibration . . . 31
O3.1-814 Field Calibration of Weak Motion Seismometers using Strong Motion Accelerometers as Reference . . . 31
O3.2-175 Ruggedized Electrostatic Radionuclide Aerosol Collection as Part of RASA 2.0 . . . 32
O3.2-251 A Gamma-Gamma Coincidence Detection System for Radionuclide Aerosol Monitoring . . . 32

O3.2-267 Enhancements of FRL08: metrological connection between simulation/experimental and utilization of AI tools for coincidence matrix analysis . . . . . 33
O3.2-362 Laboratory measurements of radioxenon samples from an IMS station . . 34
O3.2-834 Enhancing 4πβ−γ Coincidence Detection with Machine Learning for Optimized Absolute Radionuclide Activity Measurement . . . . . 34
O3.2-859 Arrangements and improvements of the Brazilian Gamma-ray Spectrometry Laboratory (BRL04) for compliance with CTBTO certification requirements . . . . . 35
O3.3-110 Amorphous wire micro-magnetic sensor for OSI magnetic field mapping . 35
O3.3-604 Analysis of Seismic Ambient Noise for Resonance Seismometry OSI Technique – the FISP Method . . . . . 36
O3.3-672 Detectability of spectral changes in plants in response to ground motion . 36
O3.3-812 Locating aftershocks using sparse PSM networks . . . . . 37
O3.4-650 Multi-Physics Analysis of Nuclear Events at FOI: the Example of the 2024 CTBTO National Preparedness Exercise . . . . . 38
O3.4-850 Enhancing Data Reliability in Nuclear Monitoring: The Characteristic Curve Method for Reducing Daily Variations . . . . . 38
O3.5-061 The Multi-Channel Maximum-Likelihood (MCML) method: extension to multisource estimation and evaluation . . . . . 39
O3.5-157 Detection of Underground Nuclear Explosions Using Phase Picking Techniques in Seismic Analysis . . . . . 40
O3.5-240 Capabilities of fibre optic cables to characterize seismic and explosion events – Case study in an underground laboratory . . . . . 40
O3.5-395 Assessing deep learning for seismic array processing pipelines . . . . . 41
O3.5-435 Source discrimination and yield determination using high-frequency waveform coda envelopes . . . . . 41
O3.5-597 Azores infrasound network: Statistical analysis and characterisation of the main detections . . . . . 42
O3.6-188 Geolocating Particulate Filters from the IMS Based on Machine Learning as a Means of Identifying Anomalies . . . . . 43
O3.6-547 Radioxenon Source Localization: A Comparison of the Swedish Radioxenon Array and the CTBT International Monitoring System . . . . . 43
O3.6-799 Analysis of 12 months of radioxenon monitoring array data in the UK . . 44
O4.1-407 Tracking of fine scale infrasound IMS network performances in near real time . . . . . 44
O4.1-791 The Influence of the Auxiliary Station Lembang Indonesia on Earthquake Hypocenter Relocation Results for Earthquakes on Java Island . . . . . 45
O4.2-114 Proposing Sustainable Power Systems for Enhanced International Monitoring Systems Operations . . . . . 46
O4.2-583 Using ICT to Rapidly Deploy Geospatial and Equipment Information Management Systems for On-Site Inspections . . . . . 46
O4.2-647 Secure Data Communication for Nuclear Monitoring at the Swedish NDC 47
O4.3-165 Rapidly Changing Metadata (RCM): a Project to Add FAIR metadata to Existing Standards . . . . . 47
O4.3-565 A framework for developing Large Language Model (LLM) applications . 48
O4.4-010 Recent developments in advanced materials tailored for enhancing the longevity and sustainability of hydroacoustic stations . . . . . 48
O4.4-156 Integration of mass position monitoring and auto centering on Indonesian seismic networks . . . . . 49
O4.4-273 Full Chain In-Situ Calibration of Hydroacoustic Hydrophone Stations . . 50
O4.4-458 Towards Predictive Maintenance Strategy Through Waveform Anomaly Detection using Unsupervised Learning . . . . . 50

O4.4-885 Erosion and subsidence prevention at AS007 (BRDH) auxiliary seismic station for sustainable operation and maintenance . . . 51
O4.5-205 Recent strides in a 3-D aqueous fate and transport model . . . 51
O4.5-276 Development of OSI Forward Modelling Capacity for Non-Seismic Geophysical Techniques . . . 52
O4.5-542 An ITF framework for condensed OSI exercises . . . 53
O4.5-687 Realistic and achievable sample representativeness for the environmental sampling during an OSI . . . 53
O4.5-696 Harnessing Satellite Imagery Analysis for CTBT Verification . . . 54
O5.1-095 Wandering albatrosses ride infrasonic waves over large geographic scales 54
O5.1-186 Seasonality of sea ice extent and microbarom amplitude at high-latitude IMS infrasound stations . . . 55
O5.1-327 Verification and Modelling of Tsunami Arrival Time and Wave Height Along Thailand's Andaman Sea Coast Using an Enhanced TOAST . . . 56
O5.1-448 The Volcanic Information System: Long-Range Infrasound Monitoring of Volcanic Eruptions . . . 56
O5.1-803 Monitoring whale populations from acoustic data over large temporal and spatial scales . . . 57
O5.2-018 NDC in a box analysis of the 17-18 August 2024 Kamchatka seismo-volcanic events: opportunities for integration of the CTBTO IMS system into Kenya's preparedness for concomitant geohazards . . . 58
O5.2-265 Application of the Capacity Building System (CBS) at National Data Center (NDC) of Bangladesh . . . 58
O5.2-474 Leveraging on the Support CTBTO CBS Offers; Lessons Learnt . . . 59
O5.2-521 Strengthening National Data Centre Through Regional Empowerment: A story of Malaysia . . . 59
O5.2-828 Recent Seismic Activity & Improvements with Earthquake Monitoring in Jamaica . . . 60
O5.3-011 Leveraging social media to elevate awareness of nuclear tests vs natural earthquakes among Indonesia's diverse communities . . . 61
O5.3-360 Tech for Tolerance: Using Gamification to Drive Youth Engagement in the Nuclear-Test-Ban Treaty . . . 61
O5.3-484 A Decade of Teaching Nuclear Weapons and Arms Control: Lessons for the Future . . . 62
O5.3-773 Expanding the CTBTO's Role as a Public Communicator in Addressing Disinformation Post-Entry into Force . . . 62
OP Online Opening . . . 63
P1.1-022 Structure of the atmosphere in the form of a 'head of cabbage' from acoustic sounding data . . . 63
P1.1-035 Air quality impact on the sampling possibilities of the International Monitoring System radionuclide particulate stations . . . 64
P1.1-115 The influence of acoustic and internal gravity waves from atmospheric storms on the parameters of the upper atmosphere . . . 64
P1.1-183 Combined loss of coherence and network covering methods to improve I17CI detections by adding dummy sensors . . . 65
P1.1-227 Analysing bolide shock source and propagation variability through a case study . . . 65
P1.1-228 Investigation of anomalously fast infrasound phases from global bolide events . . . 66
P1.1-363 Studying infrasound propagation in the middle atmosphere with the upper atmosphere model UA-ICON: parameterization and characterization of gravity waves . . . 67

P1.1-422 Assessing Plume Detectability Using Multiscale Atmospheric Transport Modeling . . . 67
P1.1-557 What can we learn from a comparison of European Centre for Medium-Range Weather Forecasts and National Centers for Environmental Prediction-driven source-receptor sensitivity fields? . . . 68
P1.1-669 Numerical simulation for 3-D infrasound propagation in shadow zone using a one-way approach . . . 69
P1.1-709 Estimating gravity waves at source levels using long range infrasound waveforms . . . 69
P1.1-749 Modeling the characteristics of infrasound signals as detected from a balloon platform: Earth and Venus applications . . . 70
P1.1-794 Relation between rainfall variability and signals characteristics of infrasound events during the dry season in the central highland region of Madagascar . . . 70
P1.1-867 Optimization of Selection Methods and Localization of Infrasound Sources for Solving Problems in the Monitoring of the Comprehensive Nuclear-Test-Ban Treaty . . . 71
P1.2-008 Calibration of the local magnitude scale (M_L) for eastern Cuba . . . 71
P1.2-032 Improving the Crustal and Upper Mantle Velocity Model and Seismic Event Location Accuracy in Jordan through Integrated Analysis of Local, International Monitoring System and Non-International Monitoring System Data Using the Regional Seismic Travel Time Model . . . 72
P1.2-044 A computer code for calculating velocity structure parameters using Rayleigh wave phase velocity dispersion data . . . 73
P1.2-054 Attenuation of seismic waves in the Charlevoix seismic zone, southeastern Canada . . . 73
P1.2-055 Non-volcanic tremors along west Nusa Tenggara, Indonesia triggered by large teleseismic earthquakes . . . 74
P1.2-059 Seismicity linked to magmatism: The 2024 earthquake sequence in the fentale volcanic zone, Northern Main Ethiopian Rift . . . 74
P1.2-070 Comprehensive Seismic Study of North Sulawesi Indonesia : b-Value, z-Value, and Earthquake Recurrence Time . . . 75
P1.2-077 Spatial-Temporal Analysis of b-Values Along Fault Zones in the Central Himalayas Following the 2015 Gorkha Earthquake . . . 75
P1.2-080 Advantages of determining an earthquake focal mechanism using Distributed Acoustic Sensing data . . . 76
P1.2-083 Detection of Large Displacement due to Mw 7.5 28 September 2018 Palu Earthquake using 1 Hz High Rate GNSS Data . . . 77
P1.2-093 A New Dynamic Simulation of the Potential Main Marmara Fault Earthquake through Incorporation of Stress Perturbation due to 1912 Ganos and 1999 İzmit Earthquakes and Interseismic Stress Load . . . 77
P1.2-098 Seismotectonics and characterization of natural and man-made events at Mpape following the 2024 Abuja earthquakes in Nigeria . . . 78
P1.2-101 Empirical relationship among seismic and fault parameters on the Talysh dynamic earthquake zone (southern Azerbaijan) . . . 79
P1.2-104 Focal depth of some South Atlantic earthquakes using teleseismic P-Wave and water reverberations . . . 79
P1.2-127 Seismicity and Morphometric Studies In North Sudan . . . 80
P1.2-142 Variability of ETAS Parameters and Their Relationship with Physical Processes for Earthquake Forecasting in Africa . . . 80
P1.2-147 Significant Earthquake Scenario from the Northernmost Fault in the Aceh Region, Sumatra: Preliminary Hazard Assessment . . . 81
P1.2-168 Up to date Probabilistic Earthquake Hazard Assessment for North Africa . . . 82

P1.2-274 Two-step relocation of the seismicity of Oman . . . . . 82
P1.2-275 Probabilistic Moment Tensor Inversion for Moderate to Strong Earthquakes in Albania and Surrounding Region Using Grond . . . . . 83
P1.2-281 Seismicity of the Shkodër-Pejë Fault Zone: 50 Years Overview . . . . . 84
P1.2-288 Improving a 3-D global propagation model via SMART cables and other sea floor data . . . . . 84
P1.2-312 Data Availability and Prospects of Probabilistic Seismic Hazard Studies in the Sub-Saharan Africa Using Integrated Techniques . . . . . 85
P1.2-356 Seismicity, tectonics and radon emission measurements in central Ionian Islands (Greece) . . . . . 85
P1.2-359 Tectonic settings and neo-tectonics of the Aegean Sea as seen from space . 86
P1.2-368 Incoherent Seismic Array Processing Using Kurtosis: A Case Study from the Grane Oilfield . . . . . 87
P1.2-373 Moho Depth and Average Lithospheric Structure Beneath the Beni Suef-Siwa Sector, Egypt . . . . . 87
P1.2-377 The stress mapping in the Bolivian Orocline through probabilistic moment tensor approach . . . . . 88
P1.2-384 Application of anisotropy of magnetic susceptibility fabrics and magnetic data analysis to determine the Stress analysis and tectonic trends of Southern Eastern Desert, Egypt. . . . . 88
P1.2-388 Uncertainty Analysis of Moment Tensor Solutions for Local Earthquakes around Colombia using ISOLA2024 . . . . . 89
P1.2-398 Unusual earthquakes of the Central Kalahari Game Reserve Botswana: Anomalies in a Stable Continental Plate . . . . . 90
P1.2-413 From Normal to Strike-Slip: Stress Regime Transition in Egypt and its Implications . . . . . 90
P1.2-465 Effect of Earthquakes Epicentral Distances on Peak Ground Acceleration Values Recorded By the Egyptian Strong Motion Network (ESMN) . . . . . 91
P1.2-496 A Compilation of Ground Truth Events in Australia . . . . . 91
P1.2-497 Detect ground vibrations caused by earthquakes or explosions . . . . . 92
P1.2-512 Vulnerability and Earthquake Risk Assessment for Buildings in Kuwait Governorates, Kuwait . . . . . 92
P1.2-523 Assessment of local Seismic records and the largest earthquake magnitude in Comoro-Islands between 2017 and 2021 . . . . . 93
P1.2-537 The geodynamics of Sulawesi Island and its structures based on P wave delay time, ray-tracing, and shear wave splitting phenomena . . . . . 93
P1.2-552 Investigating the Subsurface Geometry of the Mogod Fault System in Mongolia Through Earthquake Hypocenter Relocation . . . . . 94
P1.2-592 Development of a Fault database and 1-D seismic velocity Model for Madagascar: Implication for Tectonic Studies . . . . . 95
P1.2-610 Application of the Coda Calibration Tool Methodology to Intermediate Depth Events in the Vrancea Region, Romania . . . . . 95
P1.2-615 Crustal and Upper Mantle Structure of the Kenyan Rift: Insights from Receiver Function Analysis . . . . . 96
P1.2-639 Spatial-Temporal Distribution of b-Value in Albania and its Surroundings Over the Last Decade . . . . . 96
P1.2-649 Seismic Event Discriminations in the Kumtor Deposit Area (Kyrgyzstan) . 97
P1.2-681 Advancing Focal Depth Estimation Techniques: A Case Study from Mongolia . . . . . 98
P1.2-714 Background seismicity for parts of the northern Korean peninsula . . . . . 98
P1.2-733 Shear-wave attenuation in northeastern and eastern Iran and its application in source parameters estimation of the local and regional earthquakes . . . . 99

P1.2-751 Improved event location: Relocation of the 22nd June 2024 M 4.4 earthquake in Kenya using Local and Regional Networks . . . 99
P1.2-760 A new Seismicity map for Kenya (1895 to 2020) and its implications for hazard . . . 100
P1.2-825 Seismicity in Southern Brazil: Analyzing the Nature of Events . . . 100
P1.2-829 Data Quality Assessment of CTBT Auxiliary Station Jayapura (AS41 JAY) Using Cross-Correlation Techniques . . . 101
P1.2-858 The Detection of the Earthquake Swarm of the 2013 Solomon Islands M8.0 Earthquake at Santa Cruz Islands . . . 101
P1.2-868 Comparative Analysis of Pulse-Like Ground Motion Identification and Classification Using Machine Learning Techniques . . . 102
P1.2-870 Ground Motion and Aftershock Seismicity Characteristics following the Mw 6.5 Earthquake in Paphos, Cyprus on 11 January 11 2022 . . . 103
P1.2-888 Study on epicenter accuracy based on velocity models acquired from joint inversion . . . 103
P1.3-056 Prototype tsunami database and analysis rupture duration for tsunami earthquake warning in Sumatra . . . 104
P1.3-057 Tsunami modeling and inundation area from landslide scenario due to the Rokatenda volcano eruption . . . 104
P1.3-060 Analysis of tsunami hazard potential based on a submarine earthquake scenario M 7.4 in Buleleng Regency, Bali Province . . . 105
P1.3-122 Subsea Environmental Sensing with Operational Submarine Cables . . . 106
P1.3-170 Acoustic detection of a maritime accident: The case of MOL Comfort . . . 106
P1.3-244 Propagation of sound from an explosive source placed in a shallow-water wedge or deep water near the ocean bottom . . . 106
P1.3-287 Time residuals at HA11 and HA3 for T-phases from deep earthquakes in the Ring of Fire . . . 107
P1.3-405 Detecting Seismoacoustic Events in the Arctic Ocean . . . 108
P1.3-428 Assessment of Earthquake Depth Indicators from Hydroacoustic Analysis of T-Phases . . . 108
P1.3-659 Automatic identification of sources detected by the hydroacoustic stations of the International Monitoring System . . . 109
P1.3-766 Acoustic Propagation Modelling on the Cloud . . . 109
P1.3-815 Comparative analysis of recent and historic low-frequency acoustic propagation from the island of Kauai to hydrophones at Wake Island: implications for accurate localization of impulsive signals . . . 110
P1.3-851 Interpretation of whales diving behaviour in the vicinity of IMS hydrophone triplet. . . . 111
P1.3-864 Potential tsunami disaster from volcanoes in Indonesia . . . 111
P1.4-241 Real Time Global Assessment of Tsunami Risks Using Acoustic Gravity Waves . . . 112
P1.4-254 Unveiling Hydroacoustic Signatures of Aircraft Crashes: Insights from the MH370 Case . . . 112
P1.4-380 Evolution of signals of aerosol variations, rock temperature, and crustal deformation in the far tunnel of the Baksan Neutrino Observatory during strong earthquakes In Turkey on 6 February 2023 . . . 113
P1.4-518 Seismic Signature of the 25 August 2024 Nqweba Meteorite, Eastern Cape, South Africa . . . 113
P1.4-630 Tectonic stress field in the Valley of Mexico from local seismicity . . . 114
P1.4-772 Utilization of the Auxiliary Seismic Station APG (AS37) for the Analysis of Seismicity Induced by Tropical Depressions Eta and Iota in the Karst Region of Northern Guatemala . . . 115

P2.1-161 Investigating Seismic Source Characterisation Using P/S Amplitude Ratios at Local and Near-Regional Distances: A United Kingdom Case Study . . . . 115
P2.1-174 Examining the potential for detecting simultaneous noble gas and particulate samples in the IMS RN network . . . . . 116
P2.1-225 Leveraging the OSIRIS-REx Sample Return Capsule re-entry for infrasound detection of atmospheric events . . . . . 116
P2.1-229 Assessing energy estimation methods for bolides in atmospheric monitoring 117
P2.1-238 The NPE2024 event analysis and characterization at the Kenyan National Data Centre (KE-NDC) . . . . . 117
P2.1-258 Characterizing near-source physical parameters of buried explosion sources using deep learning . . . . . 118
P2.1-285 Electromagnetic signatures of underground chemical explosions . . . . . 119
P2.1-308 Nuclear event timing with three-dimensional spatial analysis of radioxenon isotopic activity ratios . . . . . 119
P2.1-391 Yield and Depth of DPRK Explosions Inverted from Regional Seismograms Using a New Algorithm . . . . . 120
P2.1-443 Quantifying uncertainty in regional-scale seismic moment tensors . . . . 120
P2.1-471 Applying Radioxenon Isotopic Ratio for Nuclear Explosion Monitoring: Determination of Origin Time . . . . . 121
P2.1-548 Infrasound from rocket launches and reentries observed at the IMS . . . . 122
P2.1-554 Modelling complex P-wave seismograms from the 28 May 1998 Pakistan explosion . . . . . 122
P2.1-555 Moment Tensor Inversion Analysis of DPRK6 Nuclear Events Using CTBTO/IMS Data . . . . . 123
P2.1-601 Generative Neural Networks in Nuclear Test Monitoring . . . . . 123
P2.1-642 The challenging multi-technology scenario of the NPE 2024 . . . . . 124
P2.1-674 Signals of Explosions in Earthquakes: Case Studies with Spotlight Detectors 125
P2.1-685 Characterizing seismic events in a noisy urban and industrial environment 125
P2.1-716 Estimating Explosion Yields Using Fourier Neural Operators and Long-Range Infrasound Observations . . . . . 126
P2.1-797 Bayesian joint localization and characterization of infrasound events . . . 126
P2.1-811 Identification of Small Seismic Events Around Underground Nuclear Test Site in the Democratic People's Republic of Korea . . . . . 127
P2.1-836 Machine-Learning Event Classification in North-East China Using Augmented Data . . . . . 128
P2.1-861 Infrasound Signal Classification Method Based on Time-Frequency Graphs and Convolutional Neural Network . . . . . 128
P2.2-062 Seismic tracking of space debris re-entries . . . . . 129
P2.2-086 Presence of an acoustic signal on seismograms after a man-made event . . 129
P2.2-150 Neutralization of a WWII Aerial Bomb in the Port of Rijeka: Seismological Data Analysis . . . . . 130
P2.2-196 Seismic diagnostics and analysis of the consequences of a chemical explosion in an urban environment . . . . . 130
P2.2-197 A Case Study with a Mobile Seismo-Acoustic Array, RAPAR . . . . . 131
P2.2-332 Assessing Romanian infrasound stations performance for tracking repetitive explosive sources generated by military activity at near-regional ranges using IDC bulletins . . . . . 131
P2.2-337 Infrasonic and seismic source characterisation of an unknown sonic boom in the Tyrrhenian Sea . . . . . 132
P2.2-338 Earthquake early-warning alert in Israel due to a 370 T explosion in southern Lebanon, October 26th, 2024 . . . . . 132
P2.2-350 Delineation of Nuclear test event from Earthquake based on teleseismic data of PS26 station . . . . . 133

P2.2-351 Detection of an explosion at the Kakhovka HPP dam by the Ukrainian geophysical network . . . 134
P2.2-352 A Seiscomp pipeline for seismo-acoustic events . . . 134
P2.2-389 Yield and Depth of an Explosion Inverted from Regional Seismograms with Source Complexity – Illustration of the Effectiveness Using Synthetic Seismograms . . . 135
P2.2-475 Seismoacoustic Simulations & Predictions of the Source Physics Experiments SPE Phase III (RVDC): Impact on explosion monitoring & discrimination . . . 135
P2.2-580 Probabilistic Source-Type Analysis for Seismic Event Classification . . . 136
P2.2-617 Source location of oceanic transform fault earthquakes constrained by IMS hydrophone triplets in the Indian Ocean . . . 136
P2.2-620 Revisiting the DPRK nuclear tests . . . 137
P2.2-624 Colossal seismic activity of the Fentale-Dofen magmatic segment in the main Ethiopian rift from September 2024 to date: potential source for ground truth events . . . 138
P2.2-671 Mysterious Seismoacoustic Signals of Eastern Helwan Quarry Blasts, 2022 138
P2.2-706 Source Identification and Discrimination Using Nearby Infrasonic and Seismic Sensors . . . 139
P2.2-729 Distinguishing Earthquakes from Anthropogenic Events in Madagascar . 139
P2.3-002 Air activity concentration of naturally occurring radioactive material (NORM) in the environment of the Nuclear Power Research Organization, National Research and Innovation Agency, South Jakarta, Indonesia, in 2023 . . . 140
P2.3-021 The benchmarking NORM map of Oman . . . 141
P2.3-058 Nuclear research reactors as source of radioxenon from neutron activation of stable xenon? . . . 141
P2.3-065 Possible source location analysis of high 135Xe observations at IMS noble gas systems to test the hypothesis of light water reactors being the source . . 142
P2.3-071 Atmospheric dispersion modelling for a hypothetical nuclear accident . . 143
P2.3-106 Modelling of dispersion of nuclear device explosion debris in the ocean . . 143
P2.3-139 Influence of routine discharges from nuclear power plants in the Florida peninsula on the radioxenon background in the northern Caribbean Sea . . . 144
P2.3-195 Determination of turbulent diffusion coefficient using atmospheric radon concentration . . . 144
P2.3-198 Rapid and versatile radionuclide source term estimation, including host rock seepage and atmospheric venting . . . 145
P2.3-203 SATEx (Subsurface-Atmosphere Tracer Experiment): Ground truth for the atmospheric detectability of xenon emitted from an underground cavity . . . 146
P2.3-204 Coupling condensation with decay-chains: A refined model for the calculation of the radioxenon source term produced by underground nuclear explosions . . . 146
P2.3-213 Improving radioxenon background estimates based on nudging observations and machine learning . . . 147
P2.3-215 Creating time pattern models of radioxenon releases from nuclear facilities based on stack measurements . . . 147
P2.3-218 Applications in nuclear explosion monitoring using predictive source models for radioxenon discharges from nuclear facilities . . . 148
P2.3-232 Series of Chemical Explosive Experiments with Subsurface Noble Gas Transport and Atmospheric Releases . . . 149
P2.3-259 Multiscale geocharacterization of volcanic tuffs in support of source discrimination modeling . . . 149
P2.3-279 Statistical analysis of nuclear power reactor outages as sources of elevated radioxenon releases . . . 150

P2.3-286 Nudging: Making Background Predictions with Atmospheric Transport Modelling Sensitive to IMS Observations . . . 151
P2.3-290 Source term analysis of 127Xe from surface and subsurface tracer transport experiments of the PE1 series . . . 151
P2.3-294 Source Term Analysis of Xenon (STAX): 7 Years of Hardware and Software Lessons-Learned . . . 152
P2.3-296 CARATk, a new toolkit for radionuclides atmospheric transport simulation for the CHIMERE model . . . 152
P2.3-298 Transport variability of Xenon and Tritium following an Underground Explosively Driven Release . . . 153
P2.3-321 Improving Global Xe-133 Background Concentration Fields by Applying Nudging Techniques in FLEXPART-LCM . . . 154
P2.3-322 Temporal and Geographical Distribution of CTBT-Relevant Xenon Isotopes: Insights into Global Background Patterns . . . 154
P2.3-346 The Importance of Background Analysis of Xenon in Nigeria: A Study Within 4°–14° N Latitude and 3°–14° E Longitude . . . 155
P2.3-409 Radionuclide background within the African continent as monitored by the CTBTO – IMS Radionuclide network . . . 155
P2.3-416 Comparison of Xe-133 activity concentration background in the Northern and Southern Hemispheres . . . 156
P2.3-417 Estimation of Xe133 release from activity concentration measurements with background signal . . . 157
P2.3-434 Enhancing Source Estimation in CTBTO Web-Grape . . . 157
P2.3-476 End-to-end numerical simulation of explosion cavity creation and circulation processes, subsurface gas venting & transport, and prompt atmospheric releases . . . 158
P2.3-487 Results of the ongoing monitoring activities at the CTBTO station in Mauritania . . . 158
P2.3-515 Review of data from radionuclide monitoring (RN64) station from 1 January 2010 to 31 October 2024; Insights and Recommendations . . . 159
P2.3-541 Attribution of the radioxenon release sources, detected by SAUNA III and three SAUNA QB networks in Lithuania . . . 160
P2.3-562 Relevance of high 135Xe/133Xe isotopic activity ratios at LWRs for nuclear explosion monitoring . . . 160
P2.3-585 Regional-Scale Air Pollution Source Identification Using Backward Particle Dynamics . . . 161
P2.3-599 Updated status and analysis of ongoing temporary noble gas background measurement campaign in Japan . . . 161
P2.3-602 Radionuclide Isotopic Ratio Analysis at Ultra-Trace Concentration Levels for CTBT Applications . . . 162
P2.3-638 Detections of the short-lived 135Xe in the natural background of xenon isotopes in the soil . . . 163
P2.3-646 Atmospheric transport modelling analyzing source regions for recurring peak detections of radioxenon at RN38 and the Pacific . . . 163
P2.3-648 Measurements of radioxenon activities during periods of gaseous release from an Advanced Gas-cooled Reactor . . . 164
P2.3-680 Cocktail-DCC method to determine radio-isotopes quantities in fall-out . 164
P2.3-682 Comparison of Belgian and Dutch results from inverse ATMs for the nuclear detonation case of NPE 2024 . . . 165
P2.3-692 Quantification of uncertainties in atmospheric transport modelling and their application to modelling radioxenon emissions . . . 166
P2.3-702 What's new in the German Radioxenon network . . . 166
P2.3-712 Extended Radionuclide Background Campaign in Pabrade, Lithuania . . . 167

P2.3-748 Characterization of Xenon-133 atmospheric civil source distribution using graph models on simulated data . . . 167
P2.3-774 Possible source origin of cesium-137 detections at station MXP44 in 2024 . 168
P2.3-779 Investigating unusual high-level radioxenon detection episodes at several locations of the IMS NG network: causes, origins and implications for radioxenon monitoring . . . 169
P2.3-820 Comparative Analysis of CFD Simulations and CTBTO Monitoring Data for Radon Displacement Detection in UNE Scenarios . . . 169
P2.3-837 Detections at Regional IMS NG Station and ATM Tracking of Possible Emission Source . . . 170
P2.3-840 Exploring bounding parameters for modeling subsurface transport of radioxenon . . . 170
P2.3-847 Temporal Trends Assessment of Atmospheric Radionuclides in Kuwait: A Long-Term Study . . . 171
P2.4-066 Analog geophysical data [from nuclear tests]: Which digitization software should I use? How can I leverage the power of AI for forensic analysis of analog data? . . . 172
P2.4-068 Vectorial Digitization and Re-Analysis of Turkey's Legacy Seismic Records: Four Major Historical Earthquakes . . . 172
P2.4-145 A Federation of Online Legacy Data Centres in Seismology (FOLDS) . . . 173
P2.4-158 Peaceful nuclear explosions at Azgir Test Site (West Kazakhstan) . . . 173
P2.4-252 From Paper to Pixels: Lessons Learnt from Creating and Using the NELD Repository . . . 174
P2.4-271 Insights on the Seismogram Database at the Timisoara Seismological Observatory, National Institute for Earth Physics, Romania . . . 175
P2.4-354 Reviewing Ground Truth Event Selection . . . 175
P2.4-426 Progress on digitization and recovery of historical U.S. nuclear test seismic data . . . 176
P2.4-427 Developing workflows for seismic patrimony . . . 176
P2.4-588 Features of the Wave Pattern of Historical Atmospheric Nuclear Explosions According to the Data of Central Asian Stations . . . 177
P2.4-675 Spatio-temporal variations of short-period S wave attenuation field in a region of the North Korea Punggye-Ri nuclear test site . . . 178
P2.4-747 Enhancing the Nuclear Explosions Waveform Repository: Integrating Data Contributions from National Institutions and Networks . . . 178
P2.4-841 Reoccupying Historic Stations and Comparing Measurements for Enhanced Characterization . . . 179
P2.4-886 Bulletin of the Central and Eastern European Infrasound Network 2023-2024 179
P3.1-063 A dense nodal array in Cartago, Costa Rica defines ground truth events and enables stacking of teleseismic waveforms from potential nuclear test explosions . . . 180
P3.1-102 VNIIA experience in seismometer development . . . 181
P3.1-167 Infrasound sensors calibration by laser pistonphone down to 1mHz . . . 181
P3.1-178 Challenges in seismometer electrical calibration: A case study preparing for a station recapitalization . . . 182
P3.1-182 Impact of temperature on GS-13 seismometer calibration results . . . 182
P3.1-233 The Role of Instrument Depth in Seismic Signal Quality: Findings from a Vertical Array at Glasgow Observatory . . . 183
P3.1-300 The Role of Small Seismometers and Infrasound Sensors in On-Site Inspection (OSI) Verification for the CTBT . . . 183
P3.1-304 Ice Cover Monitoring with Distributed Acoustic Sensing (DAS) . . . 184
P3.1-311 Laboratory experiment for sustainable pressure observation at the seafloor 185
P3.1-353 Benefits of Rotational Ground Motion Measurements for OSI Activities . . 185

P3.1-376 Will Distributed Acoustic Sensing (DAS) be able to replace classical seismic instruments? . . . 186
P3.1-378 Advancing Explosion Monitoring with Distributed Acoustic Sensing: Insights from the NORFOX Fibre Array . . . 187
P3.1-415 Wind Noise Reducing System Technical Solutions Tailored to the IMS Network . . . 187
P3.1-457 Low-Cost Digitizer Based on FPGA and Raspberry . . . 188
P3.1-511 Observing the oceans and Earth with submarine cables: SMART . . . 188
P3.1-522 Field calibration of seismic instruments . . . 189
P3.1-641 Azores infrasound network: Towards a better monitoring of seismo-volcanic activity . . . 190
P3.1-694 In Situ Calibration of CTBTO Seismic Monitoring Stations in Indonesia . . . 190
P3.1-708 From errors to insights: the role of Infrasound Calibration in improving troubleshooting activities and system knowledge . . . 191
P3.1-711 Magnetic field monitoring systems compared to systems based on seismic and infrasound for monitoring active volcanoes . . . 191
P3.1-727 Advancements in quality assurance for the International Monitoring System and calibration challenges for seismic and infrasound technologies . . . 192
P3.1-738 The Algerian Network for Infrasound (ANIs) . . . 192
P3.1-742 Calibration and Quality Control in the Design and Manufacture of Seismic Instrumentation . . . 193
P3.1-754 A New Self-Calibrating Infrasound Sensor Design . . . 194
P3.1-756 Applicability of Quantum Technologies for the Enhancement of the CTBTO Verification Activities . . . 194
P3.1-800 Results from an Ultra Broad band Borehole seismometer with flat response over five decades of frequency is presented . . . 195
P3.1-842 Identification of Seismic Noise Sources and Site Characterization of the InaTEWS Permanent Seismic Network, Indonesia . . . 195
P3.1-887 Establishing a service for calibration of low frequency transfer standard microphones in the frequency range 10 mHz to 250 Hz . . . 196
P3.2-074 An alternative silver-exchanged zeolite for noble gas collection and separation . . . 197
P3.2-136 INVAP STAX monitor installation at La Reina RR (Santiago, Chile) . . . 197
P3.2-173 Array Solutions for Radioxenon Monitoring . . . 198
P3.2-176 Acoustic Agglomeration of Aerosol Particles in Benefit of RASA 2.0 . . . 198
P3.2-223 Application of indirect quantification of Xe-133m to calibration of HPGe Detector . . . 199
P3.2-237 Uncertainties in the SAUNA measurements - calibration revisited . . . 200
P3.2-263 Global and automatic analysis of radioxenons in beta-gamma spectrum. . . . 200
P3.2-266 SAUNA III: Lessons Learned . . . 201
P3.2-325 Radiological Impact Analysis of Hypothetical Space Reactor Re-Entry Using HotSpot Code . . . 201
P3.2-404 First results of world's first Snow White air sampler equipped with LaBr3 detector . . . 202
P3.2-406 A Continuous and Automatic Argon-37 Monitoring Station . . . 202
P3.2-441 Long Term Radioxenon Efficiency Calibration Study of Beta-Gamma Detectors . . . 203
P3.2-508 Increasing the resolution of a scintillation detection cell using a diffuse reflective coating and assessment of the retention of performance characteristics during aging of a protective coating made of poly-chloro-para-xylylene . . . 203
P3.2-526 Development of a background model for coincidence gamma-ray spectrometry measurements in radionuclide monitoring . . . 204

P3.2-654 Research and selection of new sorption materials for the sample processing device of the MIKS monitoring system of xenon isotopes . . . 205
P3.2-662 Ultra Sensitive Measurements of Airbourne Nuclear Debris . . . 205
P3.2-665 Inter-Comparison of FirstLook Detector Performance and Anomalies for State of Health Monitoring in Particulate Radionuclide Monitoring Systems . 206
P3.2-668 Initial Operational and Processing Experience for Data from the First Commercial Unit of the Xenon International . . . 206
P3.2-688 Big Xe sample technology . . . 207
P3.2-693 High-precision stable xenon isotope ratio measurements of atmospheric samples . . . 207
P3.2-724 Xenon International's Quality Control Source for Gain Performance Monitoring . . . 208
P3.2-763 Potential Improvements for a Radioxenon Laboratory Measurement System Operation . . . 208
P3.2-807 Calibrating a beta-gamma coincidence detector system for assay of Xe-127 209
P3.2-809 Development of a multi-detector system for identification of low-activity CTBT-relevant radionuclides . . . 210
P3.2-865 Results of the Automated and Interactive Radionuclide Reports comparison between International Data Centre (IDC) and baseline reports from National Data Centres (NDCs) . . . 210
P3.2-873 Role of the radionuclide laboratories in the IMS network . . . 211
P3.2-880 RASA 2.0: A Next Generation Aerosol Sampler/Analyzer Update . . . 211
P3.2-889 Research on Intelligent Sampling Process for Atmospheric Radioactive Xenon Based on Online Mass Spectrometry . . . 212
P3.3-007 The open source software GPRmax for simulating GPR scenarios relevant to OSI missions . . . 213
P3.3-076 Further study of the multispectral equipment based on the first OSI equipment list . . . 213
P3.3-078 Application 2-D Radial Electrical Resistivity Imaging Profiles for Delineating Subsurface Explosion Disturbance Pattern around the 18:45 GMT 17 January 2024 Ibadan, Nigeria Explosion . . . 214
P3.3-097 Main VNIIA Focus Areas Related to the CTBT Technologies . . . 215
P3.3-100 A comparison study of magnetotelluric and electrical resistivity surveys as continuation period techniques for on-site inspection . . . 215
P3.3-334 Verification technologies for the zero-yield standard . . . 216
P3.3-386 Developing an On-Site Inspection System Using Machine Learning . . . 216
P3.3-452 Increasing the Accuracy of Detection of Underground Nuclear Explosions During On-Site Inspection Based on Changes in Residual Magnetization . . . 217
P3.3-460 On-Site Inspections in Challenging Environments with Reference to Recent Volcanoes . . . 218
P3.3-502 2-D Seismic Reflection Method for Identifying Caverns Generated by Underground Nuclear Explosions in Synthetic Data . . . 218
P3.3-527 Automated workflows for rapid understanding of ACT and RES imaging potential in an OSI context . . . 219
P3.3-528 Results of 2022 and 2023 OSI Field Tests for Non-Seismic Geophysical Techniques . . . 219
P3.3-529 Subsurface Interpretation Based on Aero-Magnetic and Aero-GPR in the Cipendawa Area, Cianjur . . . 220
P3.3-556 Results of 2022 and 2023 OSI Field Tests for Seismic Techniques . . . 220
P3.3-560 Application of Electroluminescence in a Prototype for the Measurement of a Liquid Argon Scintillation . . . 221
P3.3-568 Particulate and Noble gas data assessment tool for the Working Area (PaNGWA) . . . 222

P3.3-606 Optimizing the initial and multispectral overflight configurations . . . . . 222
P3.3-607 OSI Radionuclide and Noble Gas techniques development plan past IFE . . 223
P3.3-619 Field Tests of a Data Transmission System for On-Site Inspection . . . . . 223
P3.3-629 Noble gas measurements in an OSI, lessons learned from field measurements and BUE24 . . . . . 224
P3.3-635 Application of advanced seismic waveform inversion for detection of underground cavities – a case study . . . . . 224
P3.3-645 Lessons learned from active and passive seismic surveys at a test site in Romania . . . . . 225
P3.3-651 Onshore oil and gas exploration by an active seismic method using wireless seismic system SmartSolo IGU-16HR3C series . . . . . 226
P3.3-679 Identifying, controlling and preventing cross contamination in the OSI field laboratory - Risk Assessment Cross Contamination Tool (RACC) . . . . . 226
P3.3-764 Methodology for monitoring the correctness of the transmission of data received from the devices of the CTBTO On-Site Inspectors . . . . . 227
P3.3-780 A looped inference approach for more efficient gravitational field mapping during OSI . . . . . 227
P3.3-817 Advancing the Onset-Delay-Method for Resonance Seismometry . . . . . 228
P3.3-877 The use of geological and geophysical techniques for on-site inspection, study case: Deep-seated gravitational slope deformations near the active Boconó fault, north of Bailadores, Mérida state, Venezuela . . . . . 229
P3.4-031 Enhancing Detection of Seismic Events through Data Integration of the Local Stations in the Jordan Seismological Observatory with CTBTO - IMS Network . . . . . 229
P3.4-517 NEMOS – a software framework to simulate the response from nuclear explosion detection networks . . . . . 230
P3.4-558 Seismic Risk Evaluation of Nuclear Research Reactors in Indonesia: Enhancing Monitoring and Nuclear Test Verification . . . . . 230
P3.4-852 CTBT Auxiliary Station Baumata (AS45) Data Quality Using Template Matching Technique and PSD Evaluation . . . . . 231
P3.5-028 Assessing the impact of urbanization-induced cultural noise on seismic monitoring: a case study of AS118 . . . . . 232
P3.5-037 Detection and time variations of infrasound sources using arrays deployed in Lützow-Holm Bay, Antarctica . . . . . 232
P3.5-038 Analysis of Data from Seismic Monitoring Network around Syowa Station, Antarctica . . . . . 233
P3.5-050 Data quality control of P- and S-wave picking of local earthquakes . . . . 233
P3.5-073 Application of the short time statistical analysis in significantly increasing the signal to noise ratio of inrasound, acoustic, hydroacoustic and seismic signals . . . . . 234
P3.5-099 Algorithm for on-site estimation of the time of arrival of impulse phenomena without the man in the loop . . . . . 234
P3.5-140 Automatic determination of the detection threshold of CTBTO seismological network . . . . . 235
P3.5-144 The application of artificial intelligence in exploration seismology . . . . . 236
P3.5-171 Integrating Seismic and Infrasound Technologies for Discriminating Tectonic and Quarry Explosions in Southeastern Brazil . . . . . 236
P3.5-177 Mathematical morphological filtering with a self-adaptive reconstruction technique and application to local seismic data . . . . . 237
P3.5-179 Using nonlinear thresholding of Stockwell transforms to denoise seismic waveforms . . . . . 238
P3.5-184 Geophysical Monitoring System interactive analysis updates . . . . . 238

P3.5-191 Advanced frequency-wavenumber analysis in the Geophysical Monitoring System . . . 239
P3.5-207 NPLoc: A Machine Learning Model for Earthquake Location in Permanent Seismic Network . . . 239
P3.5-226 Effect of atmospheric entry angle on uncertainties in the observed infrasound signal back-azimuths . . . 240
P3.5-245 Event location in the Geophysical Monitoring System . . . 240
P3.5-253 Recent Updates and New Features in the InfraPy Infrasound Signal Analysis Software . . . 241
P3.5-269 Assessment of the impact of interactive analysis on Primary Array Seismic stations detections associated with building the automatically produced SEL3 events . . . 242
P3.5-280 The Swedish National Seismic Network . . . 242
P3.5-317 Advancing Earthquake Localization Using Deep Learning in Gas Storage Fields . . . 243
P3.5-329 Earthquake Location Capability of the Thailand Seismic Network . . . 244
P3.5-340 Automatic event detection and localisation using 3C array and denoising by Principal Component Analysis . . . 244
P3.5-342 Earthquake-Nuclear-Explosion Discrimination Using Discrete Wavelet Transform Machine Learning (DWTML) Supervised Techniques . . . 245
P3.5-365 Infrasound Analysis of the 6 February 2023 Kahramanmaraş Earthquakes Using CTBTO Arrays . . . 245
P3.5-387 Deep learning based phase picking on seismological IMS stations . . . 246
P3.5-392 Investigating the seismicity around the DPRK test site . . . 247
P3.5-396 Analysis of the seismic event to the northwest of Costa Rica and events detected with the Portable Infrasound Station I69CR, including data from IMS stations . . . 247
P3.5-408 Application of UMAP and XGBoost to Pg and Lg wave amplitudes, waveform time series and spectrograms to identify Mining vs Earthquake Events . . . 248
P3.5-423 Application and Evaluation of Deep learning Phase Pickers for Local Aftershock Monitoring . . . 248
P3.5-429 Towards Precision Monitoring: A Scalable CNN-Based Signal Classification Framework . . . 249
P3.5-433 Seismoacoustic Monitoring of Pyroprocessing Equipment . . . 249
P3.5-442 Real Time Earthquake Detection Using YOLOv8 and Spectrogram Analysis 250
P3.5-444 Time-variable moment tensor joint inversion of traditional seismic and gradiometer data . . . 251
P3.5-468 Generation and utilization of synthetic seismograms with the Waveform Simulation Framework . . . 251
P3.5-472 Detection Capabilities and Picking Precision of Deep Learning Methods for Local Seismic Network Processing: The Case of Terceira Rift, Azores, Portugal 252
P3.5-501 The Implications of Limestone Mining to Noise Level on The Site KAPI (CTBTO) with Analysis of Power Spectral Density . . . 252
P3.5-532 Deep learning surrogate model for near real-time estimation of ground-level infrasound transmission losses . . . 253
P3.5-553 Software Engineering Aspects of Modifying and Enhancing NET-VISA to Incorporate Long Term Priors . . . 254
P3.5-569 An end-to-end LLM engineering platform for fine-tuning, evaluation and registration of custom models and adapters . . . 254
P3.5-578 Enhanced seismic monitoring integrating DAS analysis with conventional seismological analysis . . . 255
P3.5-587 CTBTO Link to the ISC Database . . . 256

P3.5-596 Improving Seismic Signal Classification Through Novel Similarity-Based Techniques . . . 256
P3.5-600 Infrasound source position by using an over-wavelength sensor array . . . 257
P3.5-611 Infrasonic Source location Using the Neighbourhood Algorithm . . . 257
P3.5-622 The NDC in a Box waveform data processing tools: current status, recent achievements and future plans . . . 258
P3.5-628 Seismic event processing using the IMS FDSN webservice and SEISAN . . . 258
P3.5-643 Evaluation of Automatic Infrasound Signal Classification via Machine Learning Deployed at the Central and Eastern European Infrasound Network . . . 259
P3.5-658 A comprehensive exploration of the IDC infrasound pipeline . . . 260
P3.5-676 Global Detection of Volcanic Activities at the International Data Centre . . . 260
P3.5-683 Infrasound analysis in the International Data Centre Operations . . . 261
P3.5-684 Comparison of KIGAM and IDC REB Analysis Results for Earthquakes Around the Korean Peninsula . . . 262
P3.5-689 Understanding phase classification throughout the International Data Centre acoustic pipeline . . . 262
P3.5-710 Geothermal Energy Exploration and Monitoring in Kenya: Using Geotool to Characterize Seismicity and Seismic Spectrum at the Menengai Geothermal Field . . . 263
P3.5-739 Analysis of the Gutenberg-Richter Law Using CTBTO SEB Data for the Americas Region . . . 263
P3.5-757 Dellys Fireball: Determination of Characteristics Using Infrasound and Seismic Detections . . . 264
P3.5-758 The Idaho National Laboratory Seismic Network: A Brief History and Overview of Current Capabilities . . . 264
P3.5-792 Survey in Deep Learning Approaches for Local to Teleseismic Earthquake Detection and Phase Picking . . . 265
P3.5-816 Impact of feature selection in the classification of seismic events with machine learning techniques . . . 266
P3.5-818 Influence of Event Definition Criteria (EDC) on IDC SHI products and possible approaches to optimize it . . . 266
P3.5-855 High-resolution analysis of spatio-temporal ambient noise variations across the IMS infrasound network . . . 267
P3.5-869 Evaluating the Contribution of Scanning Processes to the International Data Centre Seismic Event Bulletins . . . 267
P3.5-882 Statistical Comparison between the SSEB and the REB . . . 268
P3.5-890 Research on Multi-Station Phase Picking, Association and Location Based on Graph Neural Networks . . . 269
P3.6-017 Assessment of the influence of radioxenon releases from civil nuclear activities on measured air concentrations by CTBTO IMS stations using atmospheric transport modeling (ATM) . . . 269
P3.6-049 Impact of Energy Calibration in X-Ray Region on Xenon Activity Concentration Calculation under Least-Squares-Based Net Area Calculation Method . . . 270
P3.6-126 Caesium activity concentration at Eastern Europe IMS Particulate Stations in 2011 and the influence of meteorological parameters . . . 270
P3.6-200 Assessment of Anthropogenic Radionuclides detected by the International Monitoring System in the West African Sahelian band . . . 271
P3.6-220 Computer Analyst: AI/ML assisted analyses of radionuclides from high resolution gamma-ray spectra . . . 271
P3.6-347 Contribution of Bayesian methods and uncertainty quantification to source location and interpretation of IMS radionuclide measurements . . . 272

P3.6-364 Interference of natural radionuclides and detector/shielding neutron interactions with the detection of CTBT-relevant radionuclides . . . 273
P3.6-372 Comprehensive Comparison of Radionuclide Laboratory Results with IMS Radionuclide Station Results . . . 273
P3.6-394 Analysis of two years of data from the Swedish Radioxenon Array . . . 274
P3.6-550 (Re)Development of IDC software for particulate and HPGe noble gas analysis . . . 274
P3.6-559 Radioxenon sample association using a machine learning approach . . . 275
P3.6-625 Tuning alarm levels for Xenon isotope detection . . . 275
P3.6-700 20 years of Krypton-85 measurements revisited . . . 276
P3.6-793 In-core monitoring of an advanced gas-cooled nuclear reactor . . . 276
P3.6-795 Assessing the source of anomalous caesium-137 detections across Europe in September 2024 . . . 277
P3.6-831 Comparison of Approaches for Memory Effect Correction and Background Measurement in a Radioxenon Detector . . . 277
P4.1-064 Enhancing Seismic Monitoring Capabilities of Bogazici University Kandilli Observatory and Earthquake Research Institute Through Integrated AI Modules . . . 278
P4.1-152 Forest fires and IMS network: A case study of wildfire outbreak in Canada in the summer of 2023 . . . 279
P4.1-169 The present technology and future challenges of the seismic monitoring used in the International Monitoring System (IMS), CTBTO . . . 279
P4.1-206 Characterizing Seismic Stations' Detection Capabilities with Supervised Learning . . . 280
P4.1-221 Empirical Evaluation of the International Monitoring Systems Detection Capability . . . 281
P4.1-282 Seasonal variations of the magnitude residuals at IMS three-component and array seismic stations . . . 281
P4.1-283 Progress on the modernization of the IDC seismic, hydroacoustic and infrasound data processing systems . . . 282
P4.1-385 Identifying Misformed Events Using Classification Techniques and Likelihood-Based Model Fit Scores . . . 282
P4.1-519 Interactive event detection assessment of the International Monitoring System . . . 283
P4.1-637 Data Quality Assessment for Five BMKG Stations Included in the CTBTO International Monitoring System . . . 284
P4.1-666 Towards a modern and robust quality control tool based on DTK-QUALITY data . . . 284
P4.1-720 Scaling up the ATM Pipeline: Boosting Performance and Efficiency . . . 285
P4.1-745 The Five M's of Seismic Station Quality: Machines, Methods, Metadata, Monitoring, Maintenance . . . 286
P4.1-856 A comparison of IDC Reviewed Event Bulletins with a baseline from the results of the 2024 Experiment . . . 286
P4.1-872 Radionuclide IMS Network QA/QC programme . . . 287
P4.1-874 Evaluating Cs-137 Analytical Variations in IMS network particulate samples: Insights from Ten Years of IDC and Radionuclide Laboratories Results . . . 287
P4.2-048 Photovoltaic Energy Storage System Solution to Inspection Team . . . 288
P4.2-107 NDC Costa Rica and GCI-Link for Latin American data recovery for the IDC 289
P4.2-199 Virtual GCI for NDC (VPN Docker) . . . 289
P4.2-236 EU Donation to Upgrade the ASF056 Auxiliary Station Borehole Seismometer . . . 290
P4.2-306 Design and Implementation of Multi-Redundant Seismic Data Transmission with VSAT and GSM . . . 290

P4.2-318 Preliminary Design of Deep Learning-Based Link Quality Estimation Using Signal to Interference and Noise Ratio (LQE-SINR) for GSM Communication in Indonesia's Seismic Network . . . 291
P4.2-323 Perspective for SPALAX-NG improvement . . . 291
P4.2-418 Design of standardized turnkey power cabinet for remote stations . . . 292
P4.2-446 Relation About Lightening – Electricity and Monitoring Systems . . . 292
P4.2-461 Upgraded Puerto La Cruz Seismic Station (PCRV) 2023-2024: Boosting Global Seismic Monitoring and Nuclear Test Verification . . . 293
P4.2-572 IMS stations backup power: Transition to lithium batteries technology . . . 293
P4.2-574 Smart Dust based on Quantum Artificial Intelligence System for Urban Safety Against Nuclear Detection . . . 294
P4.2-612 BMKG VSAT Network Disaster Recovery Plan as Efforts to Optimize Data and Sending Information for Meteorology, Climatology and Geophysics . . . 295
P4.2-618 A Modular Approach to the New Integrated On-Site Inspections Field Laboratory Layout . . . 295
P4.2-655 NORSAR AS72/SPITS Power system upgrade and plans for Antarctic off-grid station . . . 296
P4.2-698 New Infrasound Monitoring Capabilities in Sweden . . . 296
P4.2-721 Upgrade of the Swedish auxiliary seismic array AS101 in Hagfors . . . 297
P4.2-730 Latest major upgrades at the IMS seismic stations . . . 297
P4.3-381 Feasibility Study of Internet Paths and Communication Methods in Seismic Networks in Indonesia for Earthquake Early Warning (Case Study of the Western Region of Java Island) . . . 298
P4.3-397 Implementing Observability for the Secure Web Portal . . . 299
P4.3-399 Secure Web Portal (SWP) and Elasticsearch Integration for Enhanced Data Access. . . . 299
P4.3-483 AI-Driven Detection of Malicious Codes when Integrating Data from Monitoring Technologies . . . 300
P4.3-536 Disaster Recovery in the CTBTO . . . 300
P4.3-576 Evaluating AI Code Assistants for Enhanced Software Development in CTBTO: A Modular Approach . . . 301
P4.3-609 A new system for data acquisition and storage in Kazakhstan's National Data Centre . . . 301
P4.3-652 CDStreamer: An asynchronous Transceiver Continuous Data (CD) approach for SHI raw data distribution . . . 302
P4.3-718 Challenges of building a cost-effective, resilient and secure network in Today's world - Use case: The GCI IV . . . 303
P4.3-854 Advancing Decision Making and Sustainment of Seismic and Infrasound IMS Network: From a Data-Driven Methodology to Network Summary in The Multi-Technology Integration Portal (MuTIP) . . . 303
P4.3-883 Enhancing Information Access to CTBTO Staff through Generative AI: A Smart Chat Application for Simplified Access to Complex Directives and Protocols . . . 304
P4.4-006 Documenting two decades of seismological station maintenance in Venezuela: lessons learned and future directions . . . 304
P4.4-082 The performance of back up power at KMBO primary seismic station post upgrade . . . 305
P4.4-091 Technology and human resource in operation and maintenance . . . 305
P4.4-162 Redundant communications in the tropic . . . 306
P4.4-230 Improving Detection Capabilities: The Upgrading of CTBTO Auxiliary Stations in Indonesia . . . 307
P4.4-644 Augmented State of Health Sensors for Predictive Failure analysis . . . 307

P4.4-664 Lifecycle of IMS hydroacoustic hydrophone stations, and technical approach to their sustainment . . . 308
P4.4-691 Resilient Monitoring in Extreme Conditions: Sustaining the Warramunga Seismic Array . . . 308
P4.4-717 Modelling IMS seismic and infrasound networks sustainment needs: data-driven approach for IMS sustainment Planning . . . 309
P4.4-728 Predictive Analytics for radionuclide systems of the International Monitoring System . . . 310
P4.4-744 Failure Analysis as support to enhance the sustainment of the International Monitoring System (IMS) network: existing challenges and perspectives. . . . 310
P4.4-802 Collaborating with Station Operators for Developing the International Monitoring System Sustainment Strategy . . . 311
P4.4-804 Building the International Monitoring System Sustainment Strategy through international expert consultation and collaboration . . . 311
P4.5-043 Lead Free Radiation Protection Clothing Solution for Inspection Team . . . 312
P4.5-052 Anti-Counterfeiting Total Solution to OSI . . . 312
P4.5-079 WebGL and B/S Based GIS Platform for OSI Search Logic Development and Operation Support . . . 313
P4.5-103 Real time three dimension radiation imaging Compton camera for radiation safety of base of operations . . . 314
P4.5-112 On Site Inspection: New approach to contamination control in the Field and at Base of operation. . . . 314
P4.5-189 The BUE24 Radionuclide Scenario and Updates Needed Before IFE . . . 315
P4.5-217 Challenges of Over-Reliance on Software and Applications during CTBTO On-Site Inspections . . . 315
P4.5-242 NaIL-detector characteristics as neutron detector and gamma detector . . . 316
P4.5-268 Electronic & Magnetic Sensing Based Integrated Simulation Platform System Solution to OSI Trainings and Exercises . . . 317
P4.5-291 A realistic Inspected State Party as a required OSI integrated exercise participant for the application of the Inspection Team Functionality . . . 317
P4.5-412 Radiation protection in On-Site Inspections (OSI) . . . 318
P4.5-439 Bridging the gap between On-Site Inspection and Integrated Field Exercise 318
P4.5-513 Enhancing On-Site Inspection Capabilities Under the CTBT: Integrating Lessons from the Co-Expertise Process in Radiological Risk Communication and Stakeholder Engagement . . . 319
P4.5-538 Development of an OSI Software Package for Gravitational Field Mapping Data Processing . . . 320
P4.5-544 OSI Communications System . . . 320
P4.5-545 OSI Build-Up Exercise 2024 . . . 321
P4.5-546 OSI Integrated Field Exercise . . . 321
P4.5-561 Operationalization of the OSI Operations Support Centre . . . 322
P4.5-564 OSI Directed Exercises 2023 . . . 322
P4.5-582 Enhancing On-Site Inspection Training through Online and Computer-Based Training . . . 323
P4.5-584 Requirements and management of support infrastructure for large scale OSI exercises . . . 324
P4.5-586 OSI Health, Safety and Security . . . 324
P4.5-614 New Technology Infrastructure at the On-Site Inspection Field Laboratory 325
P4.5-621 OSI Radionuclide Techniques readiness to support the On-Site Inspection Team Functionality . . . 326
P4.5-634 Necessity of a prototype test-site for optimization of OSI training . . . 326
P4.5-705 Innovations to consider in overflight training for On-Site Inspections . . . 327

P4.5-871 Improving the Effectiveness of On-Site Inspections in the Monitoring of the Comprehensive Nuclear-Test-Ban Treaty . . . 327
P5.1-001 Open cast mine explosion confirmation in South Africa with infrasound waves recorded at station I47 . . . 328
P5.1-020 Forecasting tsunami hazards for Eastern coastal regions of India and Sri Lanka: a predictive approach to risk mitigation . . . 328
P5.1-024 Seismic hazards in Jordan: integrating regional fault systems for enhanced earthquake early warning . . . 329
P5.1-025 Tsunami modelling generated by submarine landslide (non-seismic) in the Pelabuhan Ratu area, West Java, Indonesia . . . 330
P5.1-027 Artificial intelligence and the CTBTO: a SWOT analysis in the context of 12 global megatrends . . . 330
P5.1-036 The Climate Cost of Maintaining Nuclear Deterrence: Increasing Awareness on the Synergy Between Nuclear Weapons and Climate Change . . . 331
P5.1-046 Regional Dispersion of Tephra from the Andean Volcanoes and Its Impact in Paraguay . . . 331
P5.1-067 Cosmogenic Radionuclide for Civil Application: Be-7 and Application of Trans-Equatorial Method for Northeast Monsoon Forecasting in Malaysia . . . 332
P5.1-119 Harnessing Artificial Intelligence for confidence building and treaty verification in the CTBT framework: bridging technical innovation and science diplomacy . . . 333
P5.1-137 Decadal observations of deep ocean temperature change passively probed with acoustic waves . . . 333
P5.1-231 Environmental Variation Impacts on the International Monitoring System 334
P5.1-234 The 15th anniversary of the 'Tsunami Agreement' between UNESCO and CTBTO: reflections from the past and an outlook to the future . . . 334
P5.1-243 Real-time monitoring of global seismicity, response of the public and detection of particular seismic events . . . 335
P5.1-255 Analysis of Global Seismicity in 2024 and the Occurrence of Tsunamigenic Events Using the SSEB from the IDC of the CTBTO . . . 335
P5.1-277 Effect of 2020 Taal volcano eruption on Lead-212 detection of CTBTO RN52 Station . . . 336
P5.1-284 International Monitoring System data contribution to the first building code in Bolivia (Plurinational State of) . . . 336
P5.1-326 Monitoring of high-mountain glaciers in the territory of Tien-Shan by stations of the International Monitoring System . . . 337
P5.1-331 Seismic Hazard Analysis for the Central Plain of Thailand . . . 338
P5.1-336 Occurrence of earthquake in the vicinity of Bangladesh from 2001-2024: Implications for disaster management and preparedness . . . 338
P5.1-341 Interpretation of Bolide infrasonic observation on 25 August 2024 in South Africa . . . 339
P5.1-344 Operational Applications of Atmospheric and Oceanic Diffusion Modeling at RSMC Beijing . . . 339
P5.1-348 Integrating IMS and NDC Into the National Nuclear and Radiological Emergency Response Plan to Enhance Radiological Emergency Response in Nigeria . . . 340
P5.1-371 XENAS: An overview of environmental radionuclide monitoring of pressurised water reactor . . . 340
P5.1-447 Blowing on the Wind: eDNA Profiles from CTBTO Air Filters to Monitor Biodiversity . . . 341
P5.1-551 The Necessity of Infrasound Stations for Comprehensive Monitoring in Indonesia . . . 342

P5.1-567 Imaging lava eruptions and crater morphology changes at a basaltic volcano using infrasound . . . 342
P5.1-577 The Psychological Impact of Nuclear Weapons Proliferation on Global Populations . . . 343
P5.1-581 Tsunami Wave Height Modelling Using COMCOT Software 3 Based on Maximum Earthquake Scenario in Bali Island . . . 343
P5.1-595 WMO's Role in Nuclear Emergency Response and Cooperation with CTBTO 344
P5.1-598 Promoting the Peaceful Use of IMS Data for Climate Research and Climate Change Monitoring . . . 345
P5.1-627 On the use of Be-7 observations to study atmospheric processes . . . 345
P5.1-632 The Importance of CTBTO Data in Climate Change Research . . . 346
P5.1-707 Leveraging competencies and expertise across international organizations in support of global peace and security . . . 346
P5.1-725 2011-2020: A decade of global volcanic events observations at the IMS infrasound network . . . 347
P5.1-731 CTBTO in the Face of Climate Change and Natural Disasters: How to Adapt 347
P5.1-746 The Role of CTBTO in Global Climate Change Governance: Prospects for the Pacific Island States . . . 348
P5.1-755 Global Climate Governance: Navigating the Prospects of CTBTO in Multilateral Climate Cooperation . . . 349
P5.1-785 Radionuclide Detection Variation in Europe: A Comparative Analysis Using RNToolkit . . . 349
P5.1-796 Tackling Trust in the Treaty: New Technologies and Diplomatic Strategies to Build Confidence in the CTBT(O) . . . 350
P5.1-822 Nuclear Explosions, GIS and Utilizing an Interdisciplinary Approach to Understanding Environmental Impacts . . . 350
P5.1-830 Analysis of infrasound generated by the meteoroid explosion over Japan on 29 November 2020 . . . 351
P5.1-845 Assessment of Hypocenter Accuration and Dissemination Performance of Indonesia Tsunami Eraly Warning System (INATEWS) . . . 352
P5.2-012 Growth and advancement of the Seismology Laboratory at the National Data Center of Paraguay . . . 352
P5.2-023 Analyse data in the NDC of Congo by GPMCC and Geotool . . . 353
P5.2-026 Strengthening Latin American and Caribbean engagement in CTBTO technical, scientific and diplomatic arenas . . . 353
P5.2-053 The role of Nigeria's NDC to research revolution in Nigeria: A Scientist's perspective . . . 354
P5.2-069 Difficulty to implement radiological monitoring in air in Mali . . . 354
P5.2-088 Angolan National Arms Control and Disarmament Authority (ANCAD) framework for implementing the Treaty . . . 355
P5.2-096 Advances in nuclear monitoring and Earth science research by NDCs in Africa: The West African model . . . 356
P5.2-130 Hydroacoustic activities detected in the Indian Ocean during the global outbreak of the COVID-19 pandemic . . . 356
P5.2-146 Automated Multilingual Seismic Event Reporting Module for SeisComP Pipeline Based on Python for NDCs . . . 357
P5.2-260 International cooperation in seismic monitoring across the Arabian Peninsula . . . 358
P5.2-270 The prospects of establishing an NDC in The Gambia . . . 358
P5.2-301 Precision Through Proximity: Enhancing Seismic Event Relocation with Local and Regional Networks . . . 359
P5.2-314 Improvement to Use NDC in a Box SHI in Jordan, Enhancing SHI Processing and The Technical Expertise and Issues Learned . . . 359

P5.2-339 CTBT Technologies in the Verification Regime . . . 360
P5.2-382 Benefits of the NDC in Costa Rica since 2012 and inter-institutional collaboration on the use of data from IMS monitoring technologies . . . 360
P5.2-401 Mainshock-Aftershocks Sequences in Distinguishing Anthropogenic and Natural Quakes: Case Study Turkana Rift, East Africa . . . 361
P5.2-424 Enhancing Operational Excellence: A Comprehensive Training Strategy for IMS Station Operators . . . 361
P5.2-425 Training Cycle Approach for National Data Centres (TCAN2) . . . 362
P5.2-573 Contribution of Kazakhstan's Stations of the National Nuclear Center into Global and Regional Monitoring . . . 363
P5.2-613 Advanced Capacity Building System in Iraqi NDC and Event Data Analysis 363
P5.2-616 Overcoming challenges of science outreach: Leveraging mobile technology for earthquake education in Latin America . . . 364
P5.2-697 Participation of the Austrian and the Mongolian NDCs to the CTBTO Mentoring Programme . . . 364
P5.2-778 Increasing the availability and safety by integrating CTBTO station and NDC Facilities as sensitive digital asset in the Framework of national cybersecurity programme . . . 365
P5.2-781 Empowering Venezuelan Seismological Service for Scientific and Civil Applications: Integrating IMS Technologies and Capacity-Building for Enhanced Regional Monitoring . . . 365
P5.2-789 A proposal to transfer Botswana National Data Center to a University environment . . . 366
P5.2-808 Benefits of installation of Capacity Building System at NDC of Mexico . . . 367
P5.2-813 The Role of Technology and Analyst Expertise in Modern Nuclear Test Monitoring . . . 367
P5.2-819 Infrasound Signals Detected of Auroral Electrojet Arcs in 2020 by Infrasound Stations along the Arctic Circle Region . . . 368
P5.2-823 Seismoacoustic Analysis of 13 January 2025, Japan Earthquake . . . 368
P5.2-832 Study of Tectonic Plates Interactions Using IMS Stations: An Example of Inter-NDC Cooperation and Regional Empowerment . . . 369
P5.3-003 Covering SnT2025 Conference for African Audience . . . 370
P5.3-004 Integrating public perception and science: understanding the global awareness of the CTBTO's mission . . . 370
P5.3-051 Low-cost seismometer for earthquake risk reduction in Nepal . . . 371
P5.3-075 Seismic hazard studies in Ghana and the success story . . . 371
P5.3-132 Keep CTBT Known to the Young and the Public . . . 372
P5.3-166 Women empowerment in nuclear diplomacy, nonproliferation and disarmament: Case study of the CTBTO Mentoring Programme . . . 372
P5.3-202 The propagation of seismic waves, misinformation and disinformation from the 2024-10-05 M 4.5 Iran earthquake . . . 373
P5.3-264 Enhancing Public Awareness on the Role and Importance of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) and the RN52 Radionuclide Monitoring Station in the Philippines . . . 374
P5.3-302 Harnessing Virtual Technology to Empower Youth and Early Career Scientists for CTBT . . . 374
P5.3-310 Amplifying the CTBTO's Mission Through Art: Democratizing Science and Technology, Empowering Youth and Humanizing Nuclear Disarmament . . . 375
P5.3-393 Science and Technology Conferences (SnT): History, Accomplishments and Role in Supporting CTBT . . . 375
P5.3-419 Teaching experience of the "Application of Earth Sciences in Nuclear Test Monitoring" . . . 376

P5.3-451 Seizing the Moment: Leveraging Shifting Nuclear Attitudes to Strengthen the CTBT . . . 377
P5.3-482 Sustained Engagement of Early-Career Women in STEM: Evaluating Impact Through Key Performance Indicators (KPIs) in Indonesia's Commitment to CTBTO Initiatives . . . 377
P5.3-661 Will Annex 2 States Ever Ratify the CTBT? Tracing Policies, Analyzing Obstacles and Projecting the Future of Nuclear Test-Ban Diplomacy . . . 378
P5.3-737 Integrating CTBT Objectives into ASEAN's Regional Framework: A Pathway to Universalisation . . . 378
P5.3-769 From Devastation to Education: Leveraging Nuclear Tourism to Support the CTBT Entry into Force . . . 379
P5.3-782 The Role of the National Nuclear and Radiological Security Support Center from Moldova in Non-Proliferation Education . . . 379
P5.3-788 Strengthening the CTBT Verification Regime through the Socialization of IMS Technologies: Insights from the Permanent Exhibition ¡Habla Tierra! Venezuela, Seismic Country . . . 380
P5.3-833 Tangible Programming Learning for Visually Impaired Individuals . . . 381
P5.3-853 Promoting the CTBT in a constantly changing media landscape . . . 381
P5.3-863 CTBT Non-Ratifying Non-Annex 2 States: What Are the Reasons for Delay? Examples of Nepal, Somalia and Yemen . . . 382
Pa01 Global Innovations Part I: Waveform Technologies . . . 382
Pa02 Global Innovations Part II: Radionuclide Technologies . . . 383
Pa03 Operational detection capabilities of the CTBTO . . . 383
Pa04 The impact of extreme conditions on the CTBT monitoring . . . 383
Pa05 Machine Learning, Deep Learning, and High-Performance Computing: Transforming CTBTO's Operations in Global Monitoring and Verification . . . 384
Pa06 Geography, Gender, Generations: How NDCs Shape the World Today and Tomorrow? . . . 384
Pa07 IMS sustainment now and into the future . . . 385
Pa08 The Treaty Verification Regime across the Generations . . . 385
Pa09 Utilizing Data from On-Site Inspection activities: Insights from OSI Exercises and Field Tests . . . 385
Pa10 Today's Minds Tomorrow's Innovators - Bridging Worlds: Future Leadership for a Safer World . . . 386
Pa11 Adapt or Become Obsolete: Emerging Technologies as a Means to Achieve International Organizations' Mandates and Goals . . . 386
PTS-549 Senior Management engagement in OSIs . . . 387
PTS-805 The development of a long term strategy for the sustainment of the International Monitoring System Sustainment . . . 387
PTS-875 Enhancing the Role of National Data Centres in CTBT Verification: A Framework for Capacity Building . . . 388
PTS-881 IDC Software for NDCs, Status and Future . . . 388
SE01 The Role of Metrology in Seismic, Hydroacoustic, and Infrasound (SHI) Monitoring Activities . . . 389
SE02.02 AI at International Organizations: Opportunities and Challenges . . . 389
SE02.03 AI in the Industry: Driving Innovation, Efficiency & Growth . . . 390
SE03 Young Professionals Network (YPN): Building the next generation of specialists to carry the CTBT mission . . . 390
SE04 The Present and Future Role of DAS for NDC and Implications for the CTBTO 391
SE05 Working at the CTBTO - Recruitment Session . . . 391
SE06 Working at the CTBTO - Recruitment Session . . . 392

**Closing Plenary** / **CP**

# Closing Plenary

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**Closing Plenary with Award Ceremony**

- ES closing remarks
- Video message
- Awards Ceremony
- Closing of SnT2025 by Project Executive
- Surprise
- SnT2025 final credits

**E-mail**:

**In-person or online preference**:

**EU - CTBTO Partnership** / **EU**

# EU - CTBTO Partnership

*Openings*

**Dr Robert Floyd**, CTBTO Executive Secretary
**H.E. Ambassador Carl Hallergard**, Permanent Representative of the EU to the UN in Vienna

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*EU engagement with the CTBTO*

To highlight the long-term commitment of the EU for the CTBT, an impactful video will be screened to demonstrate how EU voluntary contributions is providing benefits to the verification regime. The video will explore achievements made possible by EU contributions "on the ground" at IMS seismic auxiliary station, at NDCs receiving Capacity Building Systems (CBS) or support for training activities, at the CTBTO with several projects enhancing verification technologies and monitoring systems, and how this support the investment of the CTBTO into the future generations of experts.

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*CTBTO Youth Group: Looking Back, Leading Forward—Together*

**Magdalene Wanyaga**, Founding Member of CYG: Reflections on the origins, values, and evolution of CYG
**Thai Ly Quoc**, Winner of Be the Voice of SnT
A youth perspective on leadership, digital storytelling, and new pathways for engagement

**E-mail**:

**In-person or online preference**:

**High-Level Plenary** / **HLP**

# High-Level Plenary

Welcome video

Opening
• Robert Floyd, CTBTO Executive Secretary

Welcome Address
• Beate Meinl-Reisinger, Foreign Minister, Austria

Keynote Addresses
• Anne-Isabelle Etienvre, Administrator General, CEA, France
• Sahle-Work Zewde, Former President, Ethiopia

Special Adresses
• Izumi Nakamitsu, United Nations Under-Secretary-General and High Representative for Disarmament Affairs (video message)
• Francisco Rondinelli Junior, President, CNEN, Brazil
• Pennapa Kanchana, Deputy Secretary-General, OAP, Thailand

Musical Interlude & IMS video

High-Level Panel Discussion
"From 90 to 100: IMS Completion Through Collaboration"
• Demberel Sodnomsambuu, President of the Mongolian Academy of Sciences, Mongolia
• Ferushka Himarua, Chief, Geo-technician at Ministry of Industries, Mines and Energy, Namibia
• Nomvelo Mkhize, Business Unit Manager, Council for GeoScience, South Africa
• Bashillah Binti Baharuddin, Research Officer, Malaysian Nuclear Agency, Malaysia

Master of Ceremonies: Sanam Shantiaei, CTBTO

**E-mail**:

**In-person or online preference**:

**Keynote on Quantum Sensing & Metrology** - Board: 0 / **Ke01**

# Quantum Sensing & Metrology: The next frontier

**Author:** Jan-Theodoor Janssen[1]

[1] *National Physical Laboratory (NPL)*

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The invention of quantum mechanics is this year a century old, and you would have thought that most its applications would have been discovered. Nothing could be further from the truth. This field of research is more active than ever before with most of the attention going to quantum computing: a new form of computing based on the principles of quantum mechanics and is predicted to outperform any form of classical computing. Although the realisation of a useful quantum computer is still some years away, there are many applications based on quantum mechanics which are here and now and extremely exciting. Using delicate quantum effects, we can make sensors which allow us to measure signals beyond classical limits, opening up a whole new world for us to explore with huge potential impact for our prosperity and our quality of life. In the field of measurement science, metrology, quantum effects have resulted in superior measurement standards which have transformed the field. In this talk I will try to explain some of the weird and wonderful aspects of quantum mechanics and discuss a number of exciting sensing applications which result from it.

**E-mail**:

**In-person or online preference**:

**Keynote on 2nd Quantum Revolution** - Board: 0 / **Ke02**

## 2nd Quantum Revolution: New Gateway to Information Technologies

**Corresponding Author:** buzek@savba.sk

Today, the second quantum revolution is unfolding across the globe, driving the development of disruptive quantum technologies with the potential to reshape science, industry, and society. These technologies promise to open new commercial frontiers, address pressing global challenges, enhance strategic security capabilities, and enable future applications that are currently beyond imagination. In this presentation, I will offer a brief overview of the emerging field of quantum information technology (QIT). To highlight the transformative potential of quantum technologies, I will begin by explaining key principles of non-relativistic quantum physics, focusing in particular on two fundamental phenomena: quantum superposition and quantum entanglement. I will also discuss the role of quantum measurements in these systems.
Finally, I will explore how QIT can support the development of innovative methods for improving nuclear test-ban monitoring, illustrating a practical application with significant global implications.

**E-mail**:

**In-person or online preference**:

**Keynote on ATM in support of radionuclide detection** - Board: 0 / **Ke03**

## ATM in support of radionuclide monitoring: an overview of operational capacities

**Corresponding Author:** sylvia.generoso@cea.fr

Atmospheric Transport Modelling (ATM) is a key component of National Data Centres (NDCs) verification capacities. ATM links the detections of radionuclides to their sources, i.e. releases of radionuclides into the atmosphere, be they particles or noble gases. As such, NDCs rely on the knowledge of atmospheric dispersion primarily to provide the best possible estimate of the release scenario – location, release rates and dates – explaining the origins of the radioactivity detected by the International Monitoring System. In doing so, NDCs are faced in particular with the challenge of radioxenon background, which is extremely variable in space and time. To this end, ATM can provide an additional method to support the NDCs in discriminating detections due to existing background from those of a potential nuclear explosion.
This presentation will provide an overview of current atmospheric transport modelling applications that support the verification capacities of NDCs. It will focus on the progress that has been made over the last ten years, and will highlight, with real-case examples, some of the topics that not so long ago were the subject of studies presented at SnT Conferences and that are today integrated into the operational capacities of NDCs, as well as presenting some of the challenges ahead.

**E-mail**:

**In-person or online preference**:

**Keynote on Numerical Weather Prediction and ECMWF / Ke04**

## Recent highlights of Numerical Weather Prediction and atmospheric composition forecasts at ECMWF: the role of observations

**Corresponding Author:** laurence.rouil@ecmwf.int

The essential role played by observation networks for improving the performance of Numerical Weather Prediction (NWP) and atmospheric composition forecasts systems is illustrated in this presentation by the ECMWF experience. The European Center on Medium range Weather Forecasts is both a research institute and a 24/7 operational service, producing global numerical weather predictions for its Member and Co-operating states and the broader community. It is also one of the entities entrusted by the European Union to implement the Copernicus services of the EU space programme: the Atmosphere monitoring (CAMS) and Climate Change monitoring (C3S) services. The development and implementation of robust and reliable numerical systems at ECMWF rely on a long experience that built upon worldclass supercomputing facilities and an amazing number of in-situ and Earth Observations datasets. ECMWF now holds one of the largest meteorological data archives. How such an infrastructure has been set-up and expanded to atmospheric composition to deal with the Copernicus challenges, and how we push the limits to make it more accurate and more resilient will be discussed, thanks to several concrete examples of the achievements and the challenges that have been or remain to be overcome.

**E-mail**:

**In-person or online preference**:

**Keynote on machine learning, deep learning and high-performance computing** - Board: 0 / **Ke05**

## Machine learning, deep learning and high-performance computing

**Corresponding Author:** e.burnaev@skoltech.ru

This talk aims to explore the potential transformative impact of machine learning, deep learning, and high-performance computing on enhancing the operational capabilities of CTBTO in global monitoring and verification. Advanced AI techniques and scalable computational resources open up an opportunity for CTBTO to improve the detection, localization, and analysis of nuclear test signatures across seismic, hydroacoustic, infrasound, and radionuclide data streams. The presentation will discuss expected advancements in data-driven models, real-time processing, and automated decision-making, which could enhance accuracy and reduce response times. Furthermore, it will consider future prospects for integrating cutting-edge AI and HPC technologies to strengthen verification efforts, aiming to ensure the effectiveness and reliability of the Treaty's monitoring regime.

**E-mail**:

**In-person or online preference**:

**Keynote on NDCs and G-cube: Geography, Gender, Generation** - Board: 0 / **Ke06**

## Bridging Worlds, Building Futures: The Evolving Role of National Data Centres

**Corresponding Author:** maggie.wanyaga@yahoo.com

In a world shaped by generational shifts, gender inclusion, and geographic diversity, the role of National Data Centres (NDCs) in advancing the CTBT verification regime is more critical and more dynamic than ever.
In this keynote, Magdalene Wanyaga a geoscientist, draws on her hands-on experience with the CTBTO's International Monitoring System (IMS), the International Data Centre (IDC), and On-Site Inspection (OSI) training to reflect on how NDCs stand at the intersection of technology, people, and policy.
She explores how NDCs are not just technical infrastructure, but human-centered institutions that hold the power to foster inclusion across genders, promote intergenerational knowledge transfer, and ensure global participation, particularly through initiatives such as the National Data Centres for All. From mentorship and capacity-building to policy engagement and representation, Magdalene outlines a vision on how NDCs can serve both as mirrors and makers of a more equitable verification community.
As the world evolves, so must the verification community. This keynote calls for intentional and inclusive investment in NDCs; ensuring that those shaping the CTBT today truly reflect the world we want to protect tomorrow.

**E-mail**:

**In-person or online preference**:

**Keynote on IMS Sustainment** - Board: 0 / **Ke07**

## Sustainment of the International Monitoring System: The Value Beyond the Strategy

**Corresponding Author:** xyoli.perez.campos@ctbto.org

The International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) comprises 170 seismic, 60 infrasound, 11 hydroacoustic and 80 radionuclide stations, along with 16 radionuclide laboratories, distributed across 89 countries worldwide. Deployment of the network began in 1996, when the Treaty was opened for signature. The initial focus was on the installation and certification of the stations. Since then, daily operations have centered on their maintenance and functionality. After 25 years of continuous service, many IMS stations are approaching the end of their operational life and require recapitalization. This process is complex, spanning multiple years and involving numerous internal and external stakeholders. To address this, reduce the already built technical debt and safeguard the investment made by States in the network, a mid- and long-term sustainment strategy has been developed. The IMS sustainment strategy is primarily guided by the expected lifespan of system components and emphasizes a shift from a reactive to a proactive approach to maintain high data availability. This is crucial, as the IMS high-quality data not only fulfills its purpose of strengthening the Treaty's verification regime but also provides valuable information for scientific research and a wide range of civil applications; such as tsunami early warning systems, earthquake hazard assessment, volcanic eruption monitoring and atmospheric studies.

**E-mail**:

**In-person or online preference**:

**Keynote on the History of the Treaty Verification Regime** - Board: 0 / **Ke08**

## The GSE story: Conceptual development of the CTBT verification system

**Author:** Rodolfo Console[1]

**Co-authors:** Paul Granston Richards[2]; Victoria Oancea[3]

[1] *Istituto Nazionale di Geofisica e Vulcanologia (INGV)*

[2] *Lamont-Doherty Earth Observatory, Columbia University*

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**Corresponding Authors:** oanceavi@leidos.com, rodolfo.console@ingv.it, richards@ldeo.columbia.edu

This keynote will present the history of the Group of Scientific Experts' (GSE) work, the Treaty negotiations and the technical rationale for the Verification Regime as we know it today.

**E-mail**:

**In-person or online preference**:

**Keynote on broadening the impact of OSI exercises and field tests** - Board: 0 / **Ke09**

## Broadening the Impact of OSI Exercises and Field Tests

**Corresponding Author:** elgabry@nriag.sci.eg

The Comprehensive Nuclear-Test-Ban Treaty, describes the sole On-Site Inspection (OSI) techniques that can be used for the verification process. Over the years, there have been rapid advances in technology which have changed the scope of equipment, software and data analysis providing both increase in efficiency and enhancement in resolution.
We are currently in the preparatory phase before the Treaty enters into force—mandated by the resolution establishing the Preparatory Commission—which designates this window as critical for compiling comprehensive operational manuals. acquiring, provisioning, and technically testing all relevant inspection equipment.
OSI Field Tests and Exercises demonstrate the current operational capabilities, which in turn, make possible the operationalization of technological advances. These exercises go far beyond ensuring equipment operational readiness. They also capture massive data sets and rich experiential information on the implementation of the OSI techniques that allow their improvement and recalibration of equipment, methods and dataflows, all in compliance with the Treaty and PrepCom resolutions. This is especially true if engagement in these activities is broadened.
By fostering greater involvement of technical experts, policy-makers, and students in analysing and utilising data from these exercises, the OSI community can generate meaningful feedback to strengthen capacities, enhance readiness, and inspire innovation. In this keynote I will explore opportunities for leveraging exercise-derived data, and propose pathways to broaden community contributions, thereby ensuring OSI techniques remain robust, future-ready, and scientifically grounded in support of global nuclear disarmament and security.

**E-mail**:

**In-person or online preference**:

**Keynote on the 28 March 2025 Myanmar Earthquake** - Board: 0 / **Ke10**

## Supershear rupture and its interpretation for the 2025 Mw7.7 Mandalay, Myanmar Earthquake

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Understanding the relationship between earthquake rupture dynamics and fault structure is fundamental to earthquake physics. The 2025 Mw7.8 Myanmar earthquake is a valuable case to advance this understanding. Here we show that the Mw7.8 Myanmar earthquake produced the longest inland rupture of near 500 km along the Sagaing fault passing through the seismic gap between Mandalay and Naypyidaw, with a fairly simple surface trace. The initial sub-shear bilateral rupture accelerated to a supershear speed as it propagated towards south and sustained for more than 200 km, as constrained by multiple seismic observations and analysis. The supershear segment coincides with complicated fault related structure. We propose that the combination of a simple fault geometry, sedimentary basin and this fault related complicated fault structure enabled the sustained supershear rupture. Our findings emphasize that observations and models encompassing more comprehensive fault related structure are crucial for advancing earthquake cycle simulations and improving seismic hazard assessments.

**E-mail**:

**In-person or online preference**:

**Keynote on the 30 July 2025 Kamchatka Earthquake** / **Ke11**

## The Kamchatka Earthquake of 2025, M8.8: Results from Regional Data Processing

**Author:** Danila Chebrov[1]

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This keynote is devoted to the strongest Kamchatka earthquake since 1952 (July 29, 2025, Mw = 8.8). This earthquake ranks among the top ten strongest events of the instrumental era. Preliminary results from processing regional data recorded by the Kamchatka Regional Seismological Observation System are presented. The seismic history of the region, tectonic setting, aftershock process, macroseismic summary, and source process features are discussed. The response of the Rapid Notification Service and the Tsunami Warning Service is outlined, and the earthquake's consequences are discussed.

**E-mail**:

**In-person or online preference**:

**Keynote on AI applied to science** - Board: 0 / **Ke12**

## AI in Medicine: Data, Models, Trust, and Global Preparedness

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Artificial Intelligence has an increasingly important role in medicine. It is used to guide treatment decisions, and to enable the development of novel therapies based on the integration of complex multi-modal data. This talk will give an overview of how AI is used in medical imaging and connected modalities to predict disease course or treatment response, or the onset of future disease for

prevention. It will high-light opportunities and challenges of AI for diagnosis and prognosis. The second part will address key issues of safety and quality of algorithms including the management of false positives and false negatives, trust, and ethical considerations. Finally, we will discuss the ZODIAC Disease Phenotype Observatory, a global initiative to detect emerging novel diseases early, and to facilitate rapid response and coordination to improve preparedness for future pandemics.

**E-mail**:

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**Online oral session** - Board: 0 / **O1.1-133**

## Model of atmospheric gravity wave perturbations and their effect on localization of infrasound field and its sources

**Author:** Igor Chunchuzov[1]

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The influence of anisotropic wind velocity and temperature inhomogeneities on the attenuation of infrasound field intensity with increasing distance from a point source and its altitude distribution is studied. The field is calculated as a function of receiver height and horizontal distance from the source using method of the pseudo-differential parabolic equation for the atmosphere with model realizations of anisotropic effective sound speed fluctuations. These realizations are obtained from the non-linear shaping model for the gravity wave perturbations, which produces the fluctuations with both the vertical and horizontal spectra consistent with the observed spectra. When propagating in the stratospheric and thermospheric wave guides the multiple scattering of infrasound field from the anisotropic fluctuations results in certain vertical wave number spectra of infrasound intensity fluctuations in the stratospheric (altitudes 30-40 km) and mesospheric layers (50-70 km). The statistical characteristics of the intensity fluctuations as a function of distance from the source (up to 2200 km) were studied

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**O1.1 The Atmosphere and its Dynamics** - Board: 0 / **O1.1-143**

## Studying the correlation between wind noise levels and topography for wind noise mapping and site selection

**Authors:** Céu Jesus[1]; Roger Waxler[2]; Claus Hetzer[2]; Lance Yarbrough[1]; Carrick Talmadge[2]; Hank Buchanan[2]; Naveen Thirunilath[2]

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Turbulent pressure fluctuations around infrasound sensors, known as wind noise, are the primary factor masking infrasound detections of interest, such as signals generated by natural hazards. Identifying deployment sites with sufficiently low wind noise levels is crucial for achieving good signal to noise ratios. Noise levels are expected to correlate with local topography, which influences wind flow patterns and turbulence. This study investigates the relationship between wind noise levels and topographic features to support wind noise mapping and optimal sensor site selection. Wind noise data were collected from multiple test sites and analysed in two frequency bands: 0.1–1 Hz and 1–10 Hz. RMS pressure levels were calculated for each band, and Kernel Density Estimation was applied to estimate probability density functions. The associated cumulative distribution functions provide the probability of noise levels falling below specific thresholds, offering a statistical characterization of wind noise at each site. Topographic data were derived from remote sensing techniques, including LiDAR and satellite imagery, to analyse ground elevation, vegetation density, and canopy height. A framework for understanding wind noise behavior across varying topographic conditions, supporting the development of effective methodologies for wind noise mapping and site selection, is developed.

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**O1.1 The Atmosphere and its Dynamics** - Board: 0 / **O1.1-155**

# Observation of fireworks to understand the nonlinear behavior of shock waves excited by explosions

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As infrasound sensors have become more compact and highly accurate, the true picture of various phenomena is becoming clearer through precise and dense observation.
Considering such kind of background, we attempted to observe the infrasound signals generated by explosion events to understand the actual state of waveform deformation and attenuation due to propagation. We know that the infrasound signals of explosion events have been extremely researched in the past, but we would like to take another look at these signals. The target event was fireworks as part of theme park events. Taking advantage of the fact that such fireworks were regularly launched on every weekend of the holiday season, observations were made by deploying a portable pressure sensor near the launch site or several kilometers from the sound source. Although each observation was conducted at one or two locations, fireworks were held with the same programme every time, so we believe that we were able to obtain the almost same results as observing one event at multiple locations at the same time. Such observations made it possible to clearly see waveform deformation in the signal propagation process produced by the explosive event, especially the non-linear behavior of the shock wave.

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**O1.1 The Atmosphere and its Dynamics** - Board: 7 / **O1.1-324**

# Towards a tool to assess and update atmospheric specifications in the middle atmosphere using microbarom observations

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The oceanic swell is a global and continuous source of infrasound known as microbaroms. The infrasound stations of the International Monitoring System routinely detect microbaroms depending on acoustic waveguides that form in the middle atmosphere (MA) and the upper atmosphere (UA), roughly between 30 and 120 km. Operational meteorological products are biased at these altitudes essentially due to the lack of measurements to constrain model predictions (notably for winds). We demonstrate how it is possible to assess atmospheric products' relative performances in the MA and the UA using an operational microbarom source model feeding a processing chain that simulates microbarom arrivals at the station. These simulations using different atmospheric specifications are compared through a metric to microbarom observations to assess the realism of the modeled propagation medium. We focus on particular middle atmospheric events like a sudden stratospheric warming or on other dynamical features at various infrasound stations. In addition to assessing relative performances of meteorological products in the MA and the UA in support of operational infrasound monitoring activities, the objective of this processing chain is to demonstrate the benefit of assimilating microbarom observations in atmospheric models.

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**O1.1 The Atmosphere and its Dynamics** / **O1.1-579**

# Tracking jetstream winds through gravity waves arriving on surface based pressure sensors

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Jet stream winds play an important role in our daily weather. Accurate wind and temperature estimations in the upper troposphere can lead to better medium to long term weather forecasts. However, continuous measurement in the upper troposphere poses challenges, resulting in relatively sparse data. This study revisits previous research done in the 1960s and 1970s, on the use of ground based pressure measurements as a measure for jet stream winds. It has been established that the jet stream can generate atmospheric gravity waves that radiate to the ground. Since the previous research done, the International Monitoring System infrasound network was established. The continuous pressure data from the International Monitoring System microbarometers holds valuable information about the jet stream. We present results from a microbarometer array in Southern Germany (IS26). The pressure data has been processed for frequencies within a range of 0.1-2 mHz, where

gravity waves are detected. Signal characteristics from the array analysis, such as direction of arrival and incidence angle, enable a detailed monitoring of the jet stream strength and direction. The characteristics of these gravity waves are compiled and compared to hourly European Centre for Medium-Range Weather Forecasts ERA5 model data and other observations, such as radiosonde balloon measurements.

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**O1.2 The Solid Earth and its Structure** - Board: 0 / **O1.2-209**

## A data driven, grid refinement approach to improve global scale regional seismic travel time prediction

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Regional seismic travel time (RSTT) is a global model (Myers et al. 2010, Begnaud et al. 2021) that rapidly predicts travel times of regional seismic phases (Pn, Sn, Pg and Lg), while accounting for key effects of the three-dimensional crustal and upper mantle structures. RSTT is currently used by the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization for regional travel times. Previous versions of the RSTT utilized a constant 1° model grid. A recent RSTT study by Babikoff et al. (2022) for the eastern Mediterranean showed that iterative data-driven grid refinement improves the resolution of P wave (Pn and Pg) tomography in the tectonically complex region. We are refining these methods to improve regional travel-time tomography globally to explore the effects of model parameterization with the decreasing grid sizes as well as trade-offs relating to the retrieved upper mantle velocity and gradient structures. We have iteratively tested grid spacings from 0.5 degrees to 0.125 degrees globally to determine optimal grid refinement, as well as using L-curve tests (i.e., plotting model roughness against travel time residual) to optimize the smoothing and damping values during the iterative grid refinement. Our initial results indicate the need for stricter data quality control with decreased model grid spacing.

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**O1.2 The Solid Earth and its Structure** - Board: 0 / **O1.2-305**

## Seismicity and Stress Field Changes in the Afar and its surroundings

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The Afar Region, located in East Africa, is characterized by significant geological dynamism due to its distinctive tectonic setting. This complexity presents both challenges and opportunities for scientific research and sustainable development. A deep understanding of the region's tectonic processes is crucial for mitigating hazards and maximizing its potential. The primary goal of this study is to re-evaluate and understand the seismotectonic framework of the Afar Region and its surrounding areas. The study focuses on three specific objectives. First, it examines seismicity and the b-value parameter to understand earthquake behavior, based on a comprehensive catalog of seismic events from 1900 to 2024, sourced from the IDC, ISC, IRIS, and ORFUES databases. Second, the study constructs focal mechanism solutions using digital waveform data extracted from the IDC and IRIS, enriching the catalog of solutions. Third, it conducts a stress tensor inversion based on the available focal mechanism solutions to better understand the regional tectonic stress. Additionally, the study investigates Coulomb stress changes for significant earthquakes in the region to explore their interrelationships. This research is vital for enhancing our understanding of seismic hazards and the complex tectonics of the Afar Region.

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**O1.2 The Solid Earth and its Structure** - Board: 0 / **O1.2-349**

## Seismic Activity in Madagascar: Study of the Origins of Moderate Magnitude Earthquakes

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Madagascar is located on the African Plate and is not intersected by any plate boundaries. Despite this, the East African Rift (EAR) extends into the island, suggesting potential tectonic influences. Given Madagascar's position within the African Plate, it would theoretically be expected to exhibit low seismic activity and relative tectonic stability. However, contrary to this assumption, the island experiences significant seismic activity, with earthquakes occurring from the northern to the southern regions.
The National Data Centre (NDC) Madagascar conducts real-time seismic monitoring through its local seismic network, which includes data from the Comprehensive Nuclear-Test-Ban Treaty Organization seismic station. Using this network, a comprehensive seismic map has been developed to analyse and understand Madagascar's seismicity. While no destructive earthquakes have been recorded to date, the local magnitudes of these events are generally less than 6 on the Richter scale, with only a few exceeding a magnitude of 5. The origin of these seismic events remains uncertain, potentially linked to microplate interactions within Madagascar, the influence of the EAR system, or other geological factors. This study focuses on analyzing earthquakes with magnitudes greater than 5 to investigate their origins and contribute to the understanding of Madagascar's seismic dynamics.

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**Online oral session** - Board: 0 / **O1.2-510**

# Image Earth's Inner Core Fine-scale Heterogeneity and Temporal Changes using IMS arrays

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Understanding the structure and dynamics of the Earth's inner core is the key to understanding the history and evolution of the Earth's magnetic field. However, knowledge about the inner core remains limited. Fine-scale (1–10 km) structures within the inner core scatter high-frequency seismic waves (ICS), providing critical insights, although detecting these signals is challenging. Using the International Monitoring System (IMS) seismic array, we constructed a three-dimensional map of the inner core fine-scale structure. Our model shows substantial increases in fine-scale heterogeneity 500–800 km beneath the inner core boundary, revealing an era of rapid growth following the delayed nucleation of the inner core. The inner core is known to rotate relative to the Earth's surface or change over years to decades. However, the reported models are controversial. We analysed the ICS data from the IMS seismic array, which is sensitive to inner core changes. We found that the inner core underwent a burst of differential rotation during 2001–2003, followed by gradual eastward super-rotation from 2003–2008. Subsequently, the inner core exhibited westward sub-rotation from 2008 to 2023. Beyond differential rotation, we identified non-rotational changes near the inner core boundary between 2004 and 2008.

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**O1.2 The Solid Earth and its Structure** - Board: 0 / **O1.2-535**

# The crustal thickness and Vp/Vs ratio in Mongolia

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Crustal thickness beneath Mongolia was determined using the teleseismic receiver function H-k stacking method, which employed waveform data from broadband seismic stations in Mongolia. The findings reveal that the crust of Mongolia thickens from east to west, with the thickness reaching 63 km in western Mongolia and 35.9 km in eastern Mongolia. In the central part of Mongolia, the average thickness of the crust is approximately 45 km. The characteristics of P-to-S converted phases and negative amplitudes in stacked receiver functions may be attributed to regional tectonostratigraphic terranes in Mongolia. Subsequently, a general map of the crustal thickness of Mongolia

was generated by combining the results of this study with those of other seismological studies and the CRUST1.0 model of the Earth's crust.

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**O1.2 The Solid Earth and its Structure** - Board: 0 / **O1.2-736**

## Enhancing Earthquake Monitoring in Namibia with an integration of IMS Stations

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Earthquake monitoring in Namibia dates back since 1900s. In 2010,Namibia's Seismological Network only had six permanent seismic stations with aging equipment that were continuously failing, making it difficult to accurately monitor earthquake activities. In 2014, a National Seismological Network expansion project commenced to completely overhaul the Network. With advent use of social media, public reports on earthquakes in Namibia spread rapidly and the Geological Survey was unable to accurately determine event parameters back then. Currently, there are ten (10) seismological stations that form the National Seismological Network of Namibia. The seismic stations are located 500km apart making it challenging to constrain micro seismicity. The recorded data is transmitted in real time via the GPRS mobile network to a centralised server in Windhoek. The tenth station, the Tsumeb station, is part of the Global Seismological Network and Incorporated Research Institutions for Seismology (GSN/IRIS) that contributes to worldwide earthquakes monitoring. Moreover, it is also one of the CTBTO's IMS AS067 and IS35 monitoring of worldwide nuclear explosions. The national seismic data is primarily used for earthquake hazard assessment used for civil scientific applications. Additionally, the network provides data to the International Seismological Centre in the UK for Global Seismic Hazard profiling.

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**O1.3 The Oceans and their Properties** - Board: 0 / **O1.3-172**

## T-phases Recorded by the IMS Hydrophone Network from Tsunamigenic Earthquakes in Indonesia

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Indonesia is prone to tsunamis caused by seismic (e.g. submarine earthquakes) and non-seismic events (e.g. volcanic activity). Five massive tsunamigenic earthquakes with very different rupture

lengths occurred in different parts of the Sunda–Java Trench from 2004 to 2010. This work investigates T-phases recorded at IMS hydrophone stations HA1 and HA8 triggered by these five earthquakes using DTK-GPMCC available in NDC-in-a-box. In addition to T-phases that provide direct information about the epicenter and rupture length, earlier T-phase arrivals, due to seismic to hydroacoustic coupling far from the epicenter, and later arrivals, due to reflections from islands and seamounts, are identified. Results show that the rupture lengths of the earthquakes varied from approximately 300 to 1300 km leading to signals related to the rupture lasting from 200 to 800 s at the hydrophone stations. The obtained rupture lengths are compared to previous estimations calculated based on seismic data. Overall, results based on IMS hydrophone data provide precise and reliable back-azimuths for determining the earthquake epicenter and rupture length. These findings highlight the potential of utilizing IMS hydrophone data for a rapid rupture length assessment of tsunamigenic earthquakes in the Sunda–Java Trench.

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**O1.3 The Oceans and their Properties** - Board: 0 / **O1.3-278**

## The CTBT IMS: a window into a century of global soundscapes (1920-2020)

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Sound energy density between 50 and 100 Hz in the northeast Pacific Ocean increased roughly in proportion with global shipping tonnage in the second half of the 20th century, consistent with expectation for ambient sound dominated by contributions from distant shipping. Increases were larger in the frequency range 10-40 Hz than can be explained by increased tonnage alone, with largest increases in the 32 and 40 Hz decidecade bands. We constructed a global sound energy budget using a theoretical model that estimates the contributions from ships and baleen whales to the total. We calibrated the energy budget using measurements from six hydroacoustic stations from the Comprehensive Nuclear-Test-Ban Treaty International Monitoring System (IMS), supplemented by measurements in the northeast Pacific and northwest Atlantic Oceans. The IMS and sound energy model, combined with known or estimated changes in the number of sound sources, provide a window through which we can view a century of past soundscapes between 1920 and 2020, analyse the sources responsible for global sound energy and thus investigate the causes of the larger than expected increases at 32 and 40 Hz.

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**O1.3 The Oceans and their Properties** - Board: 0 / **O1.3-299**

# A Portable Experimental Buoy for Coastal Acoustic Monitoring as a Potential Complement to the IMS Hydroacoustic Network: Applications on the Argentinian Continental Shelf

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Shallow-water environments, such as the Argentinian continental shelf, present challenges for monitoring underwater acoustic events due to high transmission losses (TL) at low frequencies. While the International Monitoring System (IMS) hydroacoustic network is highly proficient in detecting global low-frequency signals, its coverage in coastal zones is relatively limited due to three-dimensional propagation effects near the abrupt slope at the shelf edge. This work presents a portable passive acoustic monitoring buoy designed for deployment on the Argentinian continental shelf. This prototype represents a significant advancement in addressing the challenges of acoustic monitoring in Argentina's shallow coastal waters, providing new opportunities for scientific research. The system provides the potential to combine data from CTBTO IMS hydroacoustic stations with local measurements to analyze transmission losses and infer oceanic properties. Simulations confirm the necessity of localized monitoring to address TL challenges at low frequencies. Potential applications include scenarios such as the ARA San Juan loss (2017) and studies near the continental slope. Simulations of plausible omnidirectional acoustic source events are conducted to evaluate whether the buoy's data can complement the data recorded by IMS hydrophone stations. This cost-effective prototype offers a practical tool for enhancing maritime monitoring and understanding coastal acoustic environments.

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**O1.3 The Oceans and their Properties** - Board: 0 / **O1.3-787**

# Trends in shipping sound for all European seas from 2016 to 2050

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Monitoring and modeling of ship sound are crucial due to its large contribution to underwater ambient sound. The NAVISON (Navis Sonus) project, sponsored by the European Maritime Safety Agency (EMSA), addresses this issue by calculating hindcast (2016–2023) and forecast (2030, 2040, 2050) shipping sound maps for all European seas. These maps focus on two decidecade frequency bands (63 Hz and 125 Hz), key frequencies for assessing Good Environmental Status under the EU Marine Strategy Framework Directive. Ship source levels, computed along AIS ship tracks using a novel source model (PIANO), a semi-empirical model for continuous broadband source levels from cavitation and machinery, are used as inputs for a sound mapping tool based on the parabolic equation method. Forecast ship sound predictions include the combined effects of mitigation measures based on several scenarios involving expected changes in ship traffic, and vessel design and operation. The

data, owned and maintained by EMSA, quantifies the contribution of the different vessel categories to ambient noise, evaluates mitigation performance and enables regional comparisons of shipping sound. The methodology developed for NAVISON is equally applicable in other basins, such as the northwest Pacific Ocean, thus making it relevant to characterising CTBTO measurements at Wake Island.

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**O2.1 Characterization of Treaty-Relevant Events** - Board: 0 / **O2.1-235**

## Comparison of Inversion Methods for Calculating Full Moment Tensor Solutions using Earthquake and Announced Nuclear Test Datasets

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The full moment tensor solution (MTS) allows characterisation of the source mechanism by resolving the six independent components of the source moment tensor. Determining the proportion of isotropic and deviatoric moment released by a source is essential to distinguish between explosion and earthquake sources. However, complications occur because explosions can produce deviatoric deformation via tectonic release, and shallow depth sources cause underdetermined inversions. Here we compare MTSs from the MTTime and MTUQ packages for earthquakes and announced nuclear tests. Synthetic datasets demonstrate that subtle adjustments in time shifts and station distribution can produce variable seismic source interpretations. After tuning of station-specific time-shifts, MTSs for six announced nuclear explosions at the DPRK Test Site have large positive isotropic components, with significant deviatoric components. The collapse event following the 2017 DPRK test has a large negative isotropic component, whereas MTSs for earthquakes located near to the DPRK Test have larger deviatoric components compared to the explosions and collapse sources. In all cases the compensated linear vector dipole component is substantial, and solutions are not always stable. Care must therefore be taken in characterising the source of a seismic disturbance using moment tensor inversions.

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**O2.1 Characterization of Treaty-Relevant Events** - Board: 0 / **O2.1-309**

## Nuclear event source type characterization with three-dimensional spatial analysis of radioxenon isotopic activity ratios

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The three-dimensional (3D) spatial analysis of radioxenon isotopic activity ratios can be used to determine the source type of a nuclear event without any knowledge of the time of its generation. This method requires at least a triple detection from the same sample among the four CTBT-relevant radioxenon isotopes, which are 131mXe, 133mXe, 133Xe, and 135Xe. The 3D space of three different isotopic activity ratio axes can be turned around in such a way that the perspective along the axis of decay is chosen. In this projection to a 2D plane any entry changing over time by radioactive decay would remain in the same spot. The simulations and observations of different source types whether observed (data of Nevada Test Site releases, signatures from medical isotope production facilities and Fukushima accident data) or simulated (nuclear explosion scenarios, light water reactor operation cycles, neutron activation) are entered in the plot. A cluster analysis marks the areas in which measurements of these source types can be found. This can be used to characterize the potential source of any observation that has three isotopes measured above the detection limit.

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**Online oral session** - Board: 0 / **O2.1-453**

## Limits of explosion discrimination for monitoring efforts with machine learning

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Global seismic monitoring allows for robust real-time analysis to provide useful information about seismic events to assist in earthquake emergency response and for international monitoring efforts of underground nuclear explosions (UNE) and nuisance events. Seismic explosion data is limited but is useful ground truth information for characterization studies and has been shown to be useful data labeling in machine learning (ML). Using P-wave seismograms from digital and historical (formerly-analog) seismograms and their derivative features like radiated earthquake energy, polarity, and dominant frequency, we expand on the efforts of Barama et al. (2023) and Kong (2022) for explosion discrimination at regional and teleseismic distances. We trained a seismic source classifier using a two-branch architecture to incorporate both waveforms and physics-based features to predict three classes per station: earthquake P-wave, UNE P-wave, and noise. Here we fine tune the discriminator, investigate performance limitations, and analyzing performance on unique explosion events that could confuse the model. We anticipate that machine-learning models like our classifier system can be robust tools for monitoring efforts and can help us gain insight on what drives the ML models' prediction determinations of explosive events.

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**O2.1 Characterization of Treaty-Relevant Events** - Board: 0 / **O2.1-677**

## Status of radionuclide source location exercise for the automatic data fusion tool at the CTBTO

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The data fusion automatic pipeline at the CTBTO aims to provide the most complete summary of signals observed by the International Monitoring System (IMS) by linking event information formed from seismic, hydroacoustic and infrasound (SHI) detections with radionuclide detections. The sensitivity of an IMS station sampling period to a possible release location is estimated using backward atmospheric transport modeling (ATM) using time-inverted winds. The data fusion algorithm forms matches between SHI events and the field of regard produced by ATM simulations. Due to the large time scales and wide geographic spread of most fields of regard, the algorithm results in many potential matches, making further analysis difficult. An improvement to the data fusion automatic pipeline at the CTBTO has been proposed which has the goal of focusing fusion results on those of higher probability of radionuclide release. An exercise has been organized to gather inputs on methods to accomplish this goal with corresponding tests based on synthetic events and metrics by which methods are evaluated. This presentation demonstrates the methodologies of the exercise through application on a subset of possible algorithms. Results will show the output of the evaluation and comparison between algorithms.

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**O2.1 Characterization of Treaty-Relevant Events** - Board: 0 / **O2.1-752**

## Dynamic Graph Neural Networks for Spatio-Temporal Seismic Event Localization and Characterization with Multimodal Integration

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Research on Graph Neural Networks (GNNs) has advanced rapidly, with recent architectures successfully applied to seismological tasks such as earthquake source characterization and event association. Inspired by advancements in traffic forecasting and temporal knowledge graph completion, we propose dynamic GNNs that integrate graph convolutional layers and autoencoders to capture spatio-temporal correlations in seismic fields. Our approach is trained on thousands of earthquake

events recorded by seismic networks in California (SCSN) and France (RSN), enabling the model to learn key properties of the seismic field. Unlike traditional Graph Convolutional Networks, our method dynamically updates the graph structure, allowing it to accommodate seismic networks of arbitrary size and time-varying configurations. The trained model achieves a root-mean-square error (RMSE) of less than 0.1 when predicting earthquake magnitudes, using either broadband or narrowband signals, demonstrating strong robustness for real-time characterization. Additionally, the location accuracy scales with a characteristic length derived from the clustering properties of the network, achieving an RMSE of typically less than 10 km for the SCSN. Finally, we demonstrate how large language models (LLMs) can be integrated with GNNs to incorporate additional textual descriptions from bulletins, reports, and historical data, complementing the graph-based features extracted by GNNs.

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**O2.2 Seismoacoustic Sources in Theory and Practice** - Board: 0 / **O2.2-116**

## Automatic Detection of Seismic and Infrasonic Signals from Nuclear Explosions Based on Machine Vision

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The detection of seismic and infrasonic signals from nuclear explosions has traditionally been constructed around one-dimensional signal processing methods. However, such traditional approaches are quite different from the artificial interactive analysis and detection modes. In fact, when conducting interactive processing manually, personnel complete the relevant work by relying on the visual system rather than the auditory system. As a result, the vast and valuable experience accumulated during the artificial interactive process can hardly be effectively transferred to the automatic detection and processing procedures of seismic and infrasonic signals. In view of this, this paper innovatively proposes an automatic detection and processing scheme based on machine vision. Firstly, preprocess the one-dimensional signals, convert the one-dimensional signals that have undergone normalization processing into images and label the signal categories. Subsequently, introduce the state-of-the-art YoloV11 algorithm in the field of machine vision to carry out the training work. After the YoloV11 algorithm has been trained, it is deployed to the actual detection scene. This paper presents a large number of practical application cases, and the results show that this automatic detection and processing method for seismic and infrasonic signals from nuclear explosions based on machine vision technology demonstrates outstanding performance in practical applications.

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**O2.2 Seismoacoustic Sources in Theory and Practice** - Board: 0 / **O2.2-216**

## Seismic and acoustic signals from the 2014 'Interstellar Meteor'

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It was recently reported by Siraj & Loeb (2023) that an 'interstellar meteor', potentially part of an alien spaceship, burnt up over the Pacific Ocean in 2014. These authors attempted to use seismic data produced by the bolide to pin-point a re-entry location, from which they claimed to recover pieces of the object from the seafloor. We will show, using both seismic data and IMS infrasound data, that this identification is mistaken. Instead, we associate the seismic signal with a passing vehicle. Using data from three IMS stations, we show that the meteor's actual re-entry (regardless of whether it was interstellar or not) likely took place several hundred kilometres away, and hence the recovered material is likely unrelated to it.

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**O2.2 Seismoacoustic Sources in Theory and Practice** - Board: 0 / **O2.2-250**

# Advances in Seismoacoustic Science and Technology Based on Long-Term Network Operations

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A network of seismoacoustic arrays, each of which combine seismic and infrasonic sensors into a single integrated array design, provides a unique capability to detect, locate, and characterize various sources of mechanical waves. Since 1999, Southern Methodist University and Korea Institute of Geoscience and Mineral Resources have cooperatively designed, built, operated, and upgraded six seismoacoustic research arrays (SARAs) in South Korea. This collaboration has developed instrumentation efficiencies based on an evolutionary design, testing, installation, and operation of collocated seismic and infrasound sensors. This talk summarizes the synergy of science and technology based on SARA data over the last 26 years. Topics covered include: (1) Signal characterization of various sources, including earthquakes, volcano eruptions, mining explosions, North Korea's underground nuclear explosions, and industrial chemical explosions; (2) Improved detection capability; (3) Integrated seismoacoustic event location procedures; (4) Understanding of how the time-varying nature of the atmosphere influences signal propagation; and (5) Contributions to natural hazard mitigation. The capture of both seismic and infrasound wavefields together provides the opportunity to develop new understandings of the physical processes that generate the two types of waves and improve our understanding of wave propagation through the two media.

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**O2.2 Seismoacoustic Sources in Theory and Practice** - Board: 0 / **O2.2-410**

## Using Distributed Acoustic Sensing to observe seismicity from underground chemical explosions

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Several series of explosive experiments aimed at understanding the signals from underground chemical explosions have included seismic observations made using Distributed Acoustic Sensing (DAS). In all experiments, the spatial density of DAS provided an unprecedented context for exploring topics such as geomaterial response over the course of an explosive experimental series, the influence of geologic heterogeneity on the wavefield, and the relative influence of source versus propagation effects on measured seismic signals. These results have broadened scientists' empirical experience with DAS across a range of variables including chemical explosive type, yields, geologies, scaled ranges and scaled depths of burial. This work reviews DAS performance in three explosion series to explore the role of DAS for use in characterizing chemical explosion phenomenology. A comparison of select DAS results with traditional seismic measurements of the chemical explosions and historical theory for underground nuclear explosions revealed that the trends in the DAS observations may be valuable for enhancing seismic monitoring.

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**O2.2 Seismoacoustic Sources in Theory and Practice** - Board: 0 / **O2.2-767**

## Analysis of Infrasound signals generated by a Bolide on July 28, 2022

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Infrasound networks play an important role in detecting atmospheric events such as meteors, bolides and fireballs, significantly contributing to global monitoring and atmospheric studies. On July 28, 2022, at 01:36:08 UTC, a bolide was detected over the Pacific Ocean, near South America, at coordinates 6.0°S and 86.9°W, at an altitude of 37.5 km, velocity of 29.9 km/s and a total energy estimated at 0.68 kilotons (CNEOS, 2024). The event generated infrasound waves detected by IMS network stations, including I09BR (Brazil), I08BO (Bolivia) and I20EC (Ecuador). Although the event had

relatively low energy, below the 1 kt of TNT, threshold for which IMS infrasound stations are designed, it was successfully detected and recorded. This highlights the sensitivity of the IMS network stations in detecting bolide signals globally, even in cases of lower magnitude energy. The analysis developed in this work includes determining parameters such as wave propagation speed, dominant frequency content, azimuth and maximum amplitude. The energy values were compared with those reported in global catalogs such as Center for Near Objects Studies (CNEOS) data, reinforcing the reliability of monitoring techniques. This study illustrates the effectiveness of infrasound in detecting and characterizing atmospheric events of different energy scales.

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**O2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 0 / **O2.3-219**

## New insights into isotopic activity ratios of discharges from nuclear facilities

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Contrary to expectations based on simulations of neutron irradiation, the discharges from medical isotope production facilities (MIPFs) differ from the radioxenon isotopic activity ratios typically associated with decay chain ingrowth following a nuclear explosion whenever 131mXe is present. This discrepancy is explained in this presentation through fundamental physical principles and demonstrated using measurement data collected as part of the Source Term Analysis of Xenon (STAX) project. Another important finding from the analysis of STAX data is the correlation between specific isotopes, with the correlation coefficient varying based on the source. In cases where only one radioxenon isotope is observed, these linear dependencies can be used to estimate the expected source strength of the other isotope with the presumption that a particular model type could be the source of an event. Further relevant conclusions can be drawn from analyzing STAX data on event screening. The upper ranges of isotopic activity ratios of MIPFs and nuclear power plants are compared to the thresholds applied by the International Data Centre (IDC), which uses isotopic activity ratio screening flags to indicate a possible prompt release from a nuclear explosion.

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**O2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 0 / **O2.3-247**

# Selecting the Right Noble Gas Tracer: Balancing Experiment Needs and Practical Challenges

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Noble gas tracers play a crucial role in environmental transport experiments, offering valuable insights into gas movement and interactions in both the subsurface and atmosphere which can be used to enhance noble gas sampling strategies for On-Site Inspections (OSI) and inform noble gas source terms for the International Monitoring System (IMS). The selection of appropriate noble gas tracers can be influenced by several experimental parameters, including the duration of the experiment, sampling requirements (real-time versus discrete sampling), tracer interactions with the environment, and the practical aspects of obtaining specific tracers. This presentation will discuss the benefits and challenges associated with different noble gas isotopes, highlighting their unique properties and suitability for various transport experiments. By examining these factors, we aim to optimize tracer selection to enhance the accuracy and reliability of environmental transport studies.

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**O2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 0 / **O2.3-272**

# First results of radioxenon detections of SAUNA III and three SAUNA QB networks in Lithuania

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The SAUNA III and three SAUNA QB networks in Lithuania for radioxenon detection in the atmosphere have been successfully launched at the end of 2024. The SAUNA QB modules have been installed on the border of Lithuania: SAUNA QB in Kackonys, on the eastern border, two others SAUNA QB modules on the western and southwestern border of Lithuania at Šventoji and Kybartai towns respectively, and the SAUNA III have been sat in Vilnius. Xe isotopes are possible indicators for a nuclear explosion but are also routinely released during nuclear power plant (NPP) operation and from medical isotope production facilities. The network is designed to trace xenon emissions from civil nuclear facilities in neighboring countries. Notably, it includes two VVER1200 type reactors in Belarus, located just 25 km from the Lithuanian border and only 50 km from the capital Vilnius. By now, most often Xe-133 and Xe-131m isotopes are observed, majority of concentration values are in the range from MDC up to 10 mBq/m3 and all detected events are analyzed. The statistical backward evaluation of Xe releases from the Belorussian NPP and other Xe production sources is performed by using HYSPLIT code and employing archived meteorological data.

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**Online oral session** - Board: 0 / **O2.3-436**

## Subsurface to atmospheric transport of radionuclides using physics-based and machine learning models

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Radionuclides from underground nuclear explosions can migrate through soil and rock, eventually reaching the surface and entering the atmosphere. Once airborne, they can be carried by winds to detectors located downwind. The detectability of these radionuclides is affected by the geographical and geological features of the test site, particularly in remote areas with complex terrain, which can complicate monitoring efforts. To predict the atmospheric transport of these radionuclides accurately, advanced modeling techniques are necessary. Traditional models often fail to account for the complexities of the terrain, leading to inaccuracies in dispersion predictions. The Lawrence Livermore National Laboratory has developed a fast-running LES model called Aeolus, designed to simulate the turbulent flow of air and radionuclide dispersion in complex environments. However, long-duration simulations can be computationally expensive, limiting real-time monitoring capabilities. To address these challenges, we have created a machine learning (ML) model that utilizes data from the Aeolus to predict transport over several weeks. This model is integrated with the NUFT (Numerical Underground Flow and Transport) model, which simulates contaminant movement through porous media. By combining ML with traditional modeling, we enhance our ability to predict dispersion, improving monitoring through better pattern recognition and adaptability to varying conditions.

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**O2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 0 / **O2.3-704**

## Molten Salt Reactor (MSR) Off-Gas System Efficiency and Its Possible Impact on Radioxenon Release Trajectory Estimations

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This study examines the efficiency of off-gas systems in Molten Salt Reactors (MSRs) and their influence on radioxenon release trajectories, with implications for the International Monitoring System (IMS) under the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). Expanding on previous work analyzing radioxenon dispersion from the TMSR-LF1 reactor in China (Retnoasih, 2023), this study models radioxenon trajectories using HYSPLIT with GFS0p25 meteorological data (0000Z, 7 June 2023) over 48 hours.

Results from 28 trajectory simulations reveal that lower off-gas efficiency leads to higher radioxenon concentrations and wider dispersion, increasing the likelihood of detection at multiple IMS stations, such as RN21 in Lanzhou. Reduced efficiency also raises the probability of releasing additional radionuclides, including multiple radioxenon isotopes, which could complicate source attribution and increase the background signal at monitoring stations. Conversely, higher efficiency limits both dispersion and isotopic emissions, reducing detection probabilities and aiding in differentiating MSR

releases from nuclear explosions. These findings underscore the role of off-gas systems in controlling radionuclide transport. Understanding the relationship between reactor emissions, isotope signatures and IMS detections is essential for refining source discrimination and improving nuclear explosion monitoring under the CTBT framework.

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**O2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 0 / **O2.3-715**

## Impact of Nuisance Background on Source Location Models

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Many source-term estimation algorithms for atmospheric releases assume there is no influence from nuisance sources. However, industrial sources result in a world-wide background of xenon isotopes (Miley and Eslinger 2023) that are also useful for detecting nuclear explosions. A large synthetic data set of atmospheric samples was developed for 384 release events with varying levels of 133Xe from small simulated nuclear explosions at eighth locations over four different time periods. In addition, synthetic data were developed based on the operation of several industrial emitters of 133Xe. A source-location algorithm (Eslinger et al. 2019) designed to find a short-duration release that is confounded by long-term nuisance sources was applied to the synthetic data set. The primary study result was determining the sample concentration levels below which the synthetic releases from the simulated nuclear explosion event were indistinguishable from background.

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**O2.4 Historical Data from Nuclear Test Monitoring** - Board: 0 / **O2.4-437**

## Present and Future of Seismic Patrimony Preservation Tutorial

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Legacy seismograms contain unique data about past events, nuclear explosions among them, crucial to study and analyze past and present monitorization efforts. Unfortunately, many collections of these original data and their related accessory documentation are still in risk because of inadequate storage conditions and lack of proper recognition. At many institutions personnel and resources available are scarce and it's extremely difficult to devote part of them to improve the present situation. It is common that scientific responsibles (curators) for the collections have no direct access to basic ideas for the preservation of documents (mainly because of lack of instruction). At the CTBTO2024 workshop, we presented a beta version of the Seismic Patrimony Preservation Tutorial, devoted to ease the management of the seismic patrimony and to face some minor actions improving its preservation and use. Now that a final free pdf version has been issued, we present the scope and limitations of this first version and open the debate to pursue: a) dissemination strategies to reach as many collection curators as possible, and b) decide the next areas and topics to expand with new chapters and/or efforts.

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**O2.4 Historical Data from Nuclear Test Monitoring** - Board: 0 / **O2.4-656**

## New NMSOP chapter on analog seismogram processing

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The *New Manual of Seismological Observatory Practice*, **NMSOP**, is a compendium of seismological knowledge needed to run seismic networks and observatories. It is intended to facilitate the use and analysis of digital data acquired by seismic networks with a general focus on modern systems. Nevertheless, most of the Nuclear Explosions that occurred in history were recorded on analog seismograms, and younger generations of researchers without experience on how to use analog formats are at risk of losing access to the valuable information they contain. The collection and compilation of the knowledge needed to use these analog seismograms and bring them into the digital age is time critical as some original supports are degrading and the number of researchers familiar with them is continuously decreasing. In 2023, the CoSOI of IASPEI agreed to complement the NMSOP with a chapter devoted to *legacy seismic data.* It is intended to give new users the basic knowledge required to enable their use for research and to help facilitate their preservation and digitization. We will present the first version of this chapter, which reviews analog seismogram morphology, time accuracy and correction, instrument transfer function determination and needed trace corrections for digitization and provide key bibliographic references.

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**O2.4 Historical Data from Nuclear Test Monitoring** - Board: 0 / **O2.4-667**

## Induced seismicity in the area of nuclear test sites

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Recently, a large amount of data, indicating induced seismicity in area of large underground nuclear tests (UNE), has been accumulated. Such studies were conducted on Amchitka Island (USA), Nevada Test Site (USA) and Semipalatinsk Test Site (USSR). Researchers considered three types of impacts: seismic activity associated with the destruction of the explosion cavity, induced tectonic activity in the upper crust and impact on natural seismicity of the region.
Analysis of induced seismicity in area of test sites around the world shows that UNE's aftershocks are recorded within several weeks after the conducted UNE, as well as after a long period, what specifies geodynamic processes in areas of nuclear test conducting. The manifestations of modern induced seismicity in the territory of the Punggye-ri Test Site (DPRK) are considered according to the data of the GS RAS regional network in the Far East of Russia, as well as the Degelen site (STS), according to the data of the NNC RK network. Weak earthquakes after a long period after nuclear tests are possibly associated with the migration of deep-seated fluids in the earth's crust and upper mantle, caused by the long-term intensive impact of explosions on the geological medium.

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**O2.4 Historical Data from Nuclear Test Monitoring** - Board: 0 / **O2.4-879**

## Sustainable preservation of analogue seismic data in Germany – Digitization test and reference event source parameters

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In recent years, the seismological community has recognized the critical importance of preserving analogue seismic data. However, Germany was lacking strategies for preserving these records. Here we present the preliminary findings of our feasibility study, which evaluates the potential for digitizing all analogue seismic data in Germany.
Initial inventory of the contents of German analogue seismic data archives was successfully conducted. Information was gathered from 12 German institutions and compiled into a consolidated database. This database has been published to provide extensive insights into data collections.
Furthermore, we designed and run test to estimate the workload associated with scanning and digitizing seismic records. We collected paper seismograms from three different seismic stations over three separate one-month periods, along with metadata. These records were scanned using a variety of techniques.
Subsequently, we vectorized the data using two distinct tools and compared the outcomes.
Additionally, we analyzed a test event (Tsar Bomba, 1961) to evaluate methods for determining earthquake source parameters from digitized analogue data.
Every stage of the digitization process was precisely documented, forming a manual of guidelines that serves as a foundation for establishing a long-term strategy for preserving and digitizing analogue seismic records in Germany.

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**Online oral session** - Board: 0 / **O3.1-256**

## Pisces updates for integrating CSS3.0-like database tables and files into ObsPy workflows

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Pisces (https://lanl-seismoacoustics.github.io/pisces/) is a python-based data management library designed to facilitate interaction with seismological databases utilizing CSS3.0-like schemas. Pisces leverages existing free and open source technologies maintained by the wider seismological community to incorporate information from these databases into python workflows. Recent additions to Pisces include support for CSS3.0-like instrument response files (PAZFIR files) and the conversion of database tables to ObsPy Catalog and Inventory objects. RESP and StationXML are the community standard, and open source packages, such as ObsPy, support these formats but not PAZFIR files, making them difficult to incorporate into modern workflows. PAZFIR read and write functionality has been incorporated into Pisces allowing researchers to translate CSS3.0-like tables and files into ObsPy Response and Inventory Objects and convert StationXML files to PAZFIR files and their corresponding database tables. Inventory and Catalog object support allows researchers to query these databases and output their results directly into ObsPy objects which can then be used in python workflows. The inclusion of these features facilitates the integration of data from CSS3.0-like databases into Python-based geophysical analysis workflows and provides database support for other software packages provided by Los Alamos researchers.

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**O3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 0 / **O3.1-361**

## Infrasound uncertainty propagation: ensuring traceability from the laboratory to the field

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Confidence in the quality of infrasound measurements is at the heart of the operational requirements linked to the detection and assessment of geophysical and industrial events. The entire measurement process, from laboratory calibration to the field, must be considered to estimate the confidence level of the measurement through the associated uncertainty. As part of the European Infra-AUV (metrology for low-frequency sound and vibration) project, a field calibration campaign was performed to complete the calibration chain to the sensors in the field. This paper presents a methodology to obtain traceable measurements of the infrasound wave parameters, taking into account the entire traceable calibration chain and other uncertainty sources arising from a thorough analysis of the measurement process. We present an in situ calibration method of infrasound sensors used in conjunction with the Gabrielson on-site calibration to provide field traceability of measurements under varying environmental conditions. In the context of this application, the resulting uncertainties in the back azimuth, between 0.05 and 7°, and trace velocity between 0.2 and 60 m/s (from high to low frequency), were predominantly due to the Gabrielson phase uncertainty. The amplitude uncertainty of approximately 0.2 dB also had significant contributions from the temperature and pressure susceptibilities.

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**O3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 0 / **O3.1-722**

## A strategy for the development of metrology to enhance the sustainment of the seismic and infrasound component of the IMS network

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With the majority of the Comprehensive Nuclear-Test-Ban (CTBT) International Monitoring System (IMS) network now fully operational, management of the network is undergoing a significant transition from establishing capability towards sustainment. The challenge is not limited to maintaining these capabilities, but extends to optimising the IMS network performance and providing the best possible data to make them as informative as possible to all relevant users. Metrology has an important role in this challenge. The metrology for infrasound sensors has developed since several years, advancing the approach to seismic monitoring: as an example, novel methods of infrasound on-site calibration and the application of measurement traceability have been successfully developed. Although there are still several areas for further developments in infrasound technology, some recent innovations are ready to be transferred to seismic sensing. These developments have multiple aspects and require the contribution of multiple stakeholders, working in cooperation with the Provisional Technical Secretariat (PTS). The coordination of such efforts needs careful planning and a systematic strategy identifying priorities, goals and necessary steps to be taken to align with the sustainment strategy of the PTS. This work will describe the strategy, technical contents and achievements for infrasound and seismic technologies.

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**O3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 0 / **O3.1-761**

## Exploring the Potential of a Barometer as a Transfer Standard for Infrasound Calibration

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Confidence in the quality of infrasound measurements is essential for meeting operational requirements in the detection and assessment of geophysical events. This confidence is partly established through accurate calibration of the instrumentation, encompassing the entire measurement process, from laboratory calibration to field deployment and calibration. In this process, transfer standards play a critical role in ensuring the traceability of measurements, from a primary reference standard to field applications. While microphones are commonly used for this purpose across a wide frequency range, their sensitivity diminishes and instabilities arise at lower frequencies, particularly below 0.1 Hz. In the ultra-low-frequency domain, barometers, such as the Keller PAA33X, offer a viable alternative. This study presents calibration results for the Keller PAA33X barometer used as a dynamic sensor, comparing methodologies involving a dynamic primary calibration system, a laser pistonphone and a static calibration approach. The findings provide valuable insights into the performance and reliability of barometers for infrasound measurements at ultra-low frequencies.

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## Field Calibration of Weak Motion Seismometers using Strong Motion Accelerometers as Reference

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Traceable calibration of broadband weak-motion seismometers is an ongoing challenge. In a specialized laboratory, verification of the response up to the upper corner frequency is achievable, but at a typical lower corner period accuracy is limited by parasitic tilts. Since such primary calibrations are not practical in the field, it has been proposed instead to use lab-calibrated reference seismometers in field calibrations, but then accuracy is limited at high frequency by the stiffness of the coupling

between the sensors and other factors. There is, furthermore, the question of the stability of the response of the reference sensor with time and temperature.

We propose strong-motion accelerometers as an alternative reference. These instruments have several attractive characteristics. First, the response is flat to acceleration down to zero frequency. Second, some models have both a clip level high enough to measure the acceleration due to gravity and a noise floor low enough to resolve ocean microseisms. These properties mean absolute calibration of the reference can be performed on-site and relative calibration can be done in a side-by-side test. We demonstrate such a calibration and show how this could be part of routine traceable field calibration of IMS instrumentation.

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## Ruggedized Electrostatic Radionuclide Aerosol Collection as Part of RASA 2.0

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Creare has developed an electrostatic precipitator (ESP) for high volume atmospheric aerosol collection. Previously, we demonstrated a laboratory-based ESP system with limited flow rates. With this work, we have demonstrated well over 80% collection efficiencies of 0.2–0.3 μm particles at significantly higher flow rates and lower pressure drop than the current RASA system. The particles are collected on a flexible medium that can be packaged into a small volume and placed next to a high-resolution germanium detector. An eighth-scale system has been designed, built and tested using atmospheric air, in a range of temperatures and humidities with excellent performance. We have demonstrated robust autonomous control of the blower and power supplies and have drawn numerous samples through the system. We are now building the full-scale system for long duration deployment and testing, with results expected by autumn 2025. The system performance is expected to exceed CTBT specifications for particle collection efficiencies at over twice the flow rate of the current RASA system while consuming significantly less power. If successful, this will allow the potential to sample at shorter time intervals than the current 24 hour specification.

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## A Gamma-Gamma Coincidence Detection System for Radionuclide Aerosol Monitoring

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An effort is underway to update the Radionuclide Aerosol Sampler Analyzer that is currently deployed by the International Monitoring System with one of the objectives being to increase the frequency of sample collection while maintaining or improving detection sensitivity. Detection efficiency will be increased using a pair of high purity germanium detectors, which will surround the sample also allowing for the use of coincidence spectroscopic techniques. The design of a prototype detector system is underway, which will be coupled to an electrostatic precipitation collection system. A combination of modelling studies and measurements with a representative prototype are being undertaken to predict detection performance for IMS-relevant radionuclides with different combinations of collection, decay and count times. The status of the prototype design and predicted performance will be presented.

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# Enhancements of FRL08: metrological connection between simulation/experimental and utilization of AI tools for coincidence matrix analysis

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FRL08 operates a system for very low-level measurement of fission products, named Gamma3. In addition to classical gamma spectrometry, it can operate in coincidence mode. The low probability of coincidence events is compensated by high signal-to-noise ratio and much lower detection limits, facilitating the qualitative and quantitative characterizations of samples with a large number of fission products. However, challenges arise when calculating coincidence efficiencies, which are necessary for quantifying activities and when analyzing of coincidence matrices, which are computationally intensive objects.
This work proposes an approach using Monte Carlo simulations to calculate detection efficiencies for coincidence measurements and construct a database for an artificial intelligence tool. To ensure the metrological connection between the experiment and the simulation, the digital models have first been validated for direct spectrometry using radioactive sources.
For the qualitative approach, AI tool is in development to analyze β/γ and γ/γ matrices. In terms of quantification, the coincidence detection efficiencies are retrieved from simulated spectra with the Region Of Interest (ROI) method and are applied to the experimental results. The hybrid approach and AI tool were tested on fresh fission product samples and provided results that are encouraging for further research in this direction.

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## Laboratory measurements of radioxenon samples from an IMS station

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Laboratory measurements of air samples can be used as a complement to measurements at the IMS station. Such measurements are performed today on a regular basis for the particulate stations within the IMS. Laboratory re-measurements of radioxenon samples, however, are not yet fully implemented in the verification regime. To study the benefits and restrictions for re-measurements of radioxenon samples a comparative study has been performed. During a period of 13 months a total of 91 samples from the station SEX63 has been re-measured at the nearby FOI radioxenon laboratory system. It is shown that laboratory measurement are a valuable tool for further analysis and classification of samples. The radioxenon laboratories can also be used to verify state of health parameters for the IMS systems. At the laboratory measurement parameters can be optimized for detectability of specific radioxenon isotopes. For all radioxenon isotopes, except Xe-135, measurements at the laboratory provides a better sensitivity than at the IMS station up to at least one week after the collection period.

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## Enhancing 4πβ–γ Coincidence Detection with Machine Learning for Optimized Absolute Radionuclide Activity Measurement

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This study presents a 4πβ (plastic scintillator)–γ coincidence detection system developed with the integration of machine learning to optimize the absolute activity measurement of radionuclides. A hardware setup utilizing a CAEN N5751 digitizer employed a pulse shape discrimination procedure to process signals from the detectors and generate binary list-mode files representing the measurement data. The detection system digitally acquired data by recording key features such as timing correlations, energy levels and signal shapes for each signal from the 4πβ–γ detectors. Several analysis parameter adjustments can be applied to the recorded data without requiring additional data collection experiments. In the machine learning implementation, the extracted data was used to train supervised machine learning models with a labelled dataset containing examples of true events and noise, enabling the system to classify each detected event as either true or noise. The system also performed corrections for background and decay. To determine the source activity, β efficiency was

varied using computerized discrimination methods and extrapolated to 100% efficiency. The results of our study showed excellent agreement with reference values. This research can provide valuable insights into radionuclide measurement techniques, offering a robust system for fast and accurate absolute radioactivity measurement.

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## Arrangements and improvements of the Brazilian Gamma-ray Spectrometry Laboratory (BRL04) for compliance with CTBTO certification requirements

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The International Monitoring System (IMS) of CTBTO includes sixteen radionuclide laboratories, one of them is the Brazilian Laboratory (BRL04) at the Institute of Radiation Protection and Dosimetry in Rio de Janeiro, which is not certified to analyze IMS station filters but has consistently performed well in proficiency test exercises organized by the Provisional Technical Secretariat. Currently, it performs environmental samples analysis from nuclear installations, scientific research and special samples when required. Furthermore, BRL04 provides analytical services for the export and import of commodities. This work highlights the key progress made towards certification. BRL04 has acquired two planar broad energy germanium detectors, a new filter press, and three digital signal analyzers. A skilled team, including two technical managers, a technician and an expert in gamma-ray spectrometry, is overseeing this process. In 2024, BRL04 successfully hosted two pre-certification visits from PTS members and final documentation is being prepared. The PTS has also provided training on CTBTO web-based systems, and two staff members attended a workshop at the Austrian Laboratory (ATL03) focusing on sample processing and quality management. BRL04 aims to submit for certification in the end of 2025 or early 2026, demonstrating its commitment to participate in the CTBTO radionuclide laboratory network.

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**O3.3 On-Site Inspection Relevant Techniques** - Board: 0 / **O3.3-110**

## Amorphous wire micro-magnetic sensor for OSI magnetic field mapping

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Magnetic field mapping, as one of the continued period technologies, plays a vital role for on-site inspection. Looking back into the recent science and technology development history, magnetic sensing has been under decades of development. This work would propose a high performance magnetic sensor based on the giant magnetoimpedance effect of special magnetic materials (i.e., the impedance of material changes significantly with a small change in the external magnetic field). Compared with current magnetic sensors such as GMR magnetic resistance sensors, flux metres and Hall sensors, a theorphous wire magnetic sensor has comprehensive technical advantages such as high response speed (up to MHz), high sensitivity (>1000mv/Gs), high resolution (up to 0.05nT), wide measurement range (up to ±3Gs), low power consumption (10mW), and small size (1-2 mm). A prototype UAV based magnetic field mapping equipment has been developed. Field experiments have been carried out to demonstrate its potential application to the on-site inspections of CTBT.

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**O3.3 On-Site Inspection Relevant Techniques** - Board: 0 / **O3.3-604**

## Analysis of Seismic Ambient Noise for Resonance Seismometry OSI Technique – the FISP Method

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The resonance seismometry is one of the CTBT's permitted techniques during an on-site inspection (OSI). In order to enhance the capabilities of the OSIs, we have developed a method for detecting a deep underground cavity based on the analysis of seismic ambient noise data called the Finite-Interval Spectral Power (FISP). The FISP method has become part of the draft of Concept of Operations for Resonance Seismometry. The mapping of FISP values enables the identification of the horizontal position of the cavity. The method employs single-station measurements at potentially irregularly distributed points on the Earth's free surface within the suspected cavity's area. The minimum number of receivers is 2. The grid of measurement points can be densified later if necessary. The FISP method has so far been applied to noise recordings above cavities at four different locations and environments, with different cavity depths and dimensions. We present our findings, along with the further development of the FISP method. The minimum standards required for noise measurements and instrumentation for FISP are also discussed.

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**O3.3 On-Site Inspection Relevant Techniques** - Board: 0 / **O3.3-672**

# Detectability of spectral changes in plants in response to ground motion

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Vegetation stress and its impact on plant biology is postulated as an indicator of ground motion during an underground nuclear explosion (UNE); however, its scale, longevity and detectability remain unquantified. To expand the body of work on this topic, a laboratory experiment was performed to investigate the spectral response of leaves from three evergreen plant species from different biogeographical regions to mechanical stress: Monstera sp., Ficus elastica and Alocasia gagleana. Plants were grown under both artificial and natural lighting conditions, maintaining identical environmental parameters across treatments. Spectral reflectance measurements were recorded before and after applying mechanical stress to assess the short term and long term impact of mechanical stress. Short term measurements indicate a slight reduction in reflectance in water absorption bands (1450 nm, 1950 nm) which could indicate a change in the water balance of the plants as a response to mechanical stress. In the case of long-term measurements, the most significant difference is identified between (750 nm, 1350 nm). However, in the short and long term, observed changes are within the range of measurement uncertainty. Further statistical analysis and broader research across a wider range of plants is required to assess whether vegetation stress is a detectable indicator of an UNE.

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# Locating aftershocks using sparse PSM networks

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Passive Seismic Monitoring (PSM) is the only geophysical technique allowed by the CTBT during the initial period of an on-site inspection. The goal is to reveal even the smallest expectable aftershocks of an underground nuclear explosion to the inspection team to locate the test site to the precision of a few hundreds of meters. With the full PSM network of some 50 small arrays deployed, $M_l$ -2 events can be discovered and located in the whole inspection area using the method of Nanoseismic Monitoring.

However, due to time constraints and difficult terrain, a full deployment may not be feasible. We showcase how using the same principles of Nanoseismic Monitoring, a sparse but well designed

network can perform and locate smallest aftershocks. We also present a computationally efficient AI method utilizing image recognition specifically designed for detecting such events when large sets of training data for standard machine learning are not available.

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**O3.4 Integrating Data from Different Technologies** - Board: 0 / **O3.4-650**

## Multi-Physics Analysis of Nuclear Events at FOI: the Example of the 2024 CTBTO National Preparedness Exercise

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An accurate discrimination between nuclear and conventional explosions requires a systematic analysis of signals in a wide range of physical domains, including waveforms (seismic, atmospheric infrasound and hydroacoustic waves) and radionuclides (particulates, noble gases), as well as other potential sources of information. The final joint-fusion analysis is crucial and presents several challenges, including effective communication between researchers from different scientific disciplines, accurate estimation of biases and uncertainties and their integration into the analysis, and ensuring the completeness of the event scenario space, to mention a few. In this contribution we outline the approach to fusion analysis of suspected nuclear events currently used at the Swedish Defence Research Agency (FOI). The methodology is applied to the most recent National Data Centre (NDC) Preparedness Exercise (NPE 2024), which provided an excellent opportunity for NDCs to evaluate their techniques and tools. Several scenarios were evaluated to either reinforce or dismiss, with the goal to differentiate between natural and anthropogenic sources for the various observations. Finally, we discuss challenges, potential improvements and future directions for the Swedish NDC.

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**O3.4 Integrating Data from Different Technologies** - Board: 0 / **O3.4-850**

## Enhancing Data Reliability in Nuclear Monitoring: The Characteristic Curve Method for Reducing Daily Variations

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) continuously seeks innovative methods to enhance the accuracy and reliability of its monitoring systems. This study introduces the Characteristic Curve Method, a novel approach designed to mitigate daily variations in observatory data, which pose significant challenges in the analysis and interpretation of seismic and nuclear monitoring datasets. By systematically analyzing and modeling the underlying patterns of daily variations, this method provides a robust framework for stabilizing observatory data. Preliminary results demonstrate a marked reduction in daily variation, leading to improved consistency and precision in data collected from monitoring stations. The technique utilizes characteristic curves to predict and correct daily fluctuations, enhancing the signal-to-noise ratio and facilitating more accurate event detection and characterization. We present a comprehensive examination of the Characteristic Curve Method's effectiveness across various case studies and observatory settings, highlighting its potential to improve the reliability of data used in global security and compliance monitoring. This presentation will detail the methodology, discuss its advantages over traditional approaches and outline future applications in CTBT monitoring efforts. This method can also be beneficial in Integrating different data into the database for further studies and comparative investigations.

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**O3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 0 / **O3.5-061**

# The Multi-Channel Maximum-Likelihood (MCML) method: extension to multisource estimation and evaluation

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We present a novel approach to the detection and parameter estimation of infrasonic signals: the Multi-Channel Maximum-Likelihood (MCML) method [https://doi.org/10.1093/gji/ggac377]. MCML is based on the likelihood function derived from a multi-sensor stochastic model expressed in different frequency bands. Using the likelihood function, we determine, for the detection problem, the Generalized Likelihood Ratio (GLR) associated to the p-value as a threshold and, for the estimation of the slowness vector, the Maximum Likelihood Estimation (MLE). Statistical evaluation on a synthetic dataset shows that MCML outperforms the state of the art multi-channel correlation detector algorithms like the Progressive Multi-Channel Correlation (PMCC) in terms of detection probability and false alarm rate in poor signal-to-noise ratio scenarios. MCML is applied on historical data from the International Monitoring System (IMS). We show how MCML reprocessing results overall improve the station detection capability and the characterization of the coherent background noise. A mathematical extension of MCML is implemented in order to detect overlapping coherent signals in the same time frequency domain. This extension is based on a cost-effective iterative signal deflation. This approach is evaluated through various scenarios varying signal to noise ratio (SNR), frequency bands and array geometry.

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**O3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 0 / **O3.5-157**

# Detection of Underground Nuclear Explosions Using Phase Picking Techniques in Seismic Analysis

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Accurate phase picking detection is crucial in seismic analysis, particularly in detecting underground nuclear explosions. Due to the overlapping wave characteristics, differentiation between seismic events caused by nuclear detonations and natural earthquakes is challenging. This study focuses on developing and applying advanced phase-picking techniques to identify and analyze nuclear explosions using seismic data.
The research incorporates traditional methods such as STA/LTA for detecting P- and S-wave arrivals, alongside modern machine learning algorithms like PhaseNet for enhanced accuracy and automation. The study also integrates amplitude ratio analysis (P/S and volume/surface wave ratios) and spectral discrimination to distinguish nuclear events from natural seismic sources.
Additionally, data from the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) monitoring site in Indonesia (site SIJI) were analysed. Results show that the signal to noise ratio (SNR) achieved using PhaseNet was 25.02 dB, significantly higher than the 8.216 dB obtained using STA/LTA. Results demonstrate that automated phase picking with deep learning models outperforms traditional approaches in detecting weak signals from nuclear tests, even in noisy environments. Furthermore, combining phase picking with statistical amplitude analysis significantly improves event classification accuracy. This methodology enables precise source characterization, including event location, magnitude and source type, contributing to global efforts in nuclear test monitoring.

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**O3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 0 / **O3.5-240**

# Capabilities of fibre optic cables to characterize seismic and explosion events – Case study in an underground laboratory

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Distributed Acoustic Sensing (DAS) technology using fibre optic cables presents a promising tool for detecting, locating and characterizing seismic events, including explosions. This study, based on a real experiment, assesses DAS's capability to enhance nuclear-test-ban monitoring, aligning with CTBT goals. With its ability to transform fibre optic infrastructure into extensive arrays of virtual sensors, DAS can provide high coverage monitoring suitable for remote or restricted areas. This ability presents a game changing alternative to conventional seismic networks.
The Premise-2 experiment, conducted at the Low-Noise Underground Laboratory in Rustrel (France), investigates seismic measurement using fibre optic (DAS), with a comparison to a dense network of

traditional sensors (seismometers and accelerometers). This experiment includes both active and passive seismic acquisitions, recording background noise and controlled signals. The experiment involves multiple fiber types and installation methods to examine their impact on measurement precision and signal quality, providing insights into optimizing DAS configurations for nuclear test monitoring. This technology generates a huge data volume and addresses new challenges, necessitating the development of new algorithms and workflows.

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**O3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 0 / **O3.5-395**

## Assessing deep learning for seismic array processing pipelines

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Deep learning (DL) has shown to be a powerful method for seismic phase detection for single three-component station. Here, we explore the application of DL to enhance automatic array processing pipelines for seismic event detection. Our work focuses on three key tasks where DL could complement or potentially replace traditional methods: (1) seismic phase detection, (2) seismic phase classification and back-azimuth estimation, and (3) seismic event classification. Phase picking models based on the widely used PhaseNet model, incorporating modifications such as Transformers, are used in Task (1). We investigate various approaches for this task, including phase detection using array beams, aggregating individual single-station detections from array elements and detecting on all array stations at the same time. In Task (2), we apply a DL model to process detected seismic phase arrivals on arrays. This offers a faster alternative to traditional Frequency-Wavenumber (F-K) analysis and is resilient to local and large-scale medium inhomogeneities. For Task (3), we use DL for event discrimination, specifically focusing on differentiating between earthquakes and mining-induced events. We evaluate all methods on unseen data and compare results with the classic STA/LTA based array detectors and F-K analysis. We observed clear improvements for regional events in Northern Europe.

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**O3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 0 / **O3.5-435**

## Source discrimination and yield determination using high-frequency waveform coda envelopes

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Here, we use coda measurements and apply the waveform envelope spectral ratio method to obtain the measurements necessary for source discrimination and to determine absolute yield and depth of burial at globally distributed test sites. Studies of high-frequency (>~1 Hz) source processes are crucial for both event discrimination and yield/magnitude determination of smaller seismic events. However, it is difficult to use conventional waveform methods due to the random heterogeneities in the Earth which cause scattering and produce incoherent wave trains in seismograms. To overcome this computational limitation, we neglect the seismic phase information in observed seismic waveforms and instead only utilize envelopes and/or spectrograms. Spectral ratios of envelopes of coda waveforms provide a high precision tool to study the distribution of the energy radiated by the source without requiring any prior calibration. The goal of this work is to develop a capability which allows us to better understand seismic coda and the source processes which generate it. This work demonstrations advancements in our understanding of the use of coda methods for seismic source characterization and seeks to expedite its implementation in operational settings.

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**O3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 0 / **O3.5-597**

## Azores infrasound network: Statistical analysis and characterisation of the main detections

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Monitoring techniques based on infrasound arrays have contributed to the detection, location, characterisation and quantification of volcanic and seismic activity at local as well as regional distances. Currently, the Azores infrasound network comprises an International Monitoring System (IMS) station IS42 on Graciosa Island and two low-cost arrays (SJ1 and TER), located on São Jorge and Terceira Islands. The three arrays allow monitoring the Azores area more comprehensively, improving the detection of seismo-volcanic activity, as well as enhancing characterisation of important atmospheric events such as storms and fireballs.
In this work we present a statistical analysis of infrasound detections from the updated network since June 2024, with the identification of persistent sources, variation of noise level and analysis of selected events, which allow to demonstrate its performance and sensitivity. Besides the persistent infrasound activity, we recorded other infrasound sources such as local earthquakes and airplanes. Furthermore, a first approach to correlate infrasound and seismic data from the region is also presented to try to demonstrate the benefit of this monitoring technique in the context of the archipelago.

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**O3.6 Analysis of Radionuclide Monitoring Data** - Board: 0 / **O3.6-188**

# Geolocating Particulate Filters from the IMS Based on Machine Learning as a Means of Identifying Anomalies

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The presence of radioactive particles and their nuclide mixture in the air is measured by gamma ray spectra through International Monitoring System radionuclide stations to help detect nuclear explosions. These gamma ray spectra are reported to the International Data Centre by each radionuclide station. We use supervised machine learning to show that the radionuclides present in each sample and detector characteristics are unique to each station. After collecting over 200 000 spectra and training to classify each spectra by its radionuclide station of origin, we achieved 95% balanced validation accuracy. We show how this ability stems from both the radionuclide mixture present on the filter and the electrical characteristics of the detection equipment. By indicating spectra which are unrepresentative of a certain station and flagging for possible data corruption, this capability has implications for anomaly detection within the overall International Monitoring System as a system and can therefore improve system operation. Additionally, we also achieved similar results with sequence models, which can adapt to different resolution of spectra. We also comment on the capabilities and benefits afforded by unsupervised learning for data quality analysis and other anomaly detection.

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**O3.6 Analysis of Radionuclide Monitoring Data** - Board: 0 / **O3.6-547**

# Radioxenon Source Localization: A Comparison of the Swedish Radioxenon Array and the CTBT International Monitoring System

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Between late November and early December 2022, large amounts of radioxenon were detected by multiple IMS stations and by the Swedish Radioxenon array, which at the time consisted of four SAUNA $Q_B$ detectors. In total, there were over 100 detections of Xe-133, with Xe-133m concurrently found in approximately a dozen samples. The continuous and complex nature of these detections, along with the consistent Xe-133m to Xe-133 ratio, suggests a sustained release of radioxenon presumably from a single source over several days or weeks. The Xe-133m to Xe-133 ratio was used to analyze the characteristics of the source. To identify potential source regions and estimate the source term, both backward and forward atmospheric transport models (ATM) were calculated. A grid approach was used for the forward models, matching atmospheric transport simulations at various locations to observed data. We explored the impact of restricting observational data used in the analysis to assess and compare the sparse but globally distributed IMS network to the compact but

local Swedish array. These results offer valuable insight into how a detector network configuration can enhance localization efforts of radioxenon releases.

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**O3.6 Analysis of Radionuclide Monitoring Data** - Board: 0 / **O3.6-799**

## Analysis of 12 months of radioxenon monitoring array data in the UK

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In the analysis of radioxenon sampling data from three SAUNA QB systems sited in the North of England, a variety of different approaches have been used to identify the likely source(s) of over 300 detections of Treaty-relevant isotopes of radioxenon. This work utilises stack monitoring data from both European radionuclide emitters and local sources, forward atmospheric transport & dispersion modelling (ATDM) techniques, inverse-ATDM and source reconstruction efforts. Our work demonstrates how developments in radioxenon analysis and assessment tools over the last 10+ years has greatly improved radionuclide detection analysis. This work provides a deep dive on a number of interesting detections on the array and what we have learnt from both the measurement campaign and data analysis.

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**O4.1 Performance Evaluation of the International Monitoring System** - Board: 0 / **O4.1-407**

## Tracking of fine scale infrasound IMS network performances in near real time

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Global scale infrasound observations confirm that the detection capability of the International Monitoring System (IMS) infrasound network deployed to monitor compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) is the most variable among the three waveform technologies. The time- and space-dependent dynamics of the different atmospheric layers explain the typical diurnal and seasonal trends of the network performance variability in space and time. Past global studies used station- and time-independent statistical noise models, climatological atmospheric specifications and scaling laws to estimate the minimum detectable explosive yield. In this study, a modern updated Bayesian approach has been chosen to predict as realistic as possible network detection capability with a high resolution in space and time useful to real time applications. Based on a frequency- and yield-dependent explosive source term, ECMWF operational atmospheric specifications, up to date frequency-dependent attenuation laws, measured background noise at stations, data availability of array elements, travel times of infrasound waves and performance of the operational detector, the probability to detect any explosive yield is calculated globally on an hourly basis. Results will be shown and discussed from intensive calculations carried out during the 2021-2025 time period, during which IMS infrasound network was stable, with 53 infrasound stations operational.

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**O4.1 Performance Evaluation of the International Monitoring System** - Board: 0 / **O4.1-791**

# The Influence of the Auxiliary Station Lembang Indonesia on Earthquake Hypocenter Relocation Results for Earthquakes on Java Island

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The auxiliary seismic station AS40 in Lembang, part of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) network, is also registered as a seismic monitoring station in Indonesia under the code IA LEM. In addition to its primary role in monitoring nuclear events, this station is used for earthquake location determination. This study relocated earthquake hypocenters using the HypoDD method, both with and without data from the IA LEM station. The analysis involved 92 earthquake data sets from the Java mainland (105°E – 110°E, 5°S – 7°S) for the period 2023–2024. The input parameters for both methods were standardized, and both successfully relocated 60 out of 92 earthquakes. Results show that incorporating data from the IA LEM station improved the epicentral location, with a maximum distance of 1.38 km. The average depth was 2.2 km. The ellipsoid error decreased even though the average residual with the Lembang station was 0.01 seconds higher compared to the residual without it. Based on these results, it can be concluded that the Lembang auxiliary station plays an important role in earthquake location determination, especially for high resolution location determination on the island of Java.

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**O4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 0 / **O4.2-114**

# Proposing Sustainable Power Systems for Enhanced International Monitoring Systems Operations

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The International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) operates in remote and challenging environments, where a reliable power supply is critical to ensure uninterrupted nuclear-test-ban monitoring. This study proposes integrating solar panel based power systems with real time monitoring technologies to enhance operational sustainability and efficiency. By utilizing MQTT as a proposed data transmission protocol with Quality of Service (QoS) type 2, power system parameters — such as current, voltage, State of Health (SoH) and State of Charge (SoC) — can be transmitted securely and reliably to central servers for analysis. The proposed system emphasizes renewable energy utilization, combining solar power with advanced diagnostics to reduce environmental impact and ensure long term operational stability. Additionally, implementing real time performance monitoring enables proactive maintenance, minimizing downtime and enhancing the reliability of remote stations. These innovations aim to address challenges such as energy fluctuations and power storage inefficiencies in autonomous IMS operations. Drawing inspiration from field-tested systems in meteorological monitoring stations, this proposal highlights a scalable and adaptable framework for IMS stations. By adopting these advancements, CTBTO could significantly strengthen its monitoring network's resilience and sustainability, contributing to global efforts in nuclear-test-ban verification while supporting broader goals of environmental responsibility and technological innovation.

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**O4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 0 / **O4.2-583**

# Using ICT to Rapidly Deploy Geospatial and Equipment Information Management Systems for On-Site Inspections

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Information and communication technology (ICT) has been changing rapidly and the On-Site Inspection (OSI) Division has embraced these technologies to deploy GIMO/EIMO more efficiently during an OSI. An OSI has challenging constraints of collecting, managing and storing data. Twenty years of server technologies have given organizations the ability to virtualize desktops and servers, decoupling hardware from the operating system, thus making cloud computing possible. While it is not possible to use cloud computing during an OSI, other breakthroughs have seen the decoupling of software from operating systems and packaging the application in container technologies. This

paved the way for duplication of the GIMO/EIMO application in multiple air-gapped environments and fulfils the commitment of providing ICT in a field operation environment with the ability to duplicate and deploy rapidly for an OSI.

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**O4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 0 / **O4.2-647**

## Secure Data Communication for Nuclear Monitoring at the Swedish NDC

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In the context of e.g. nuclear explosion monitoring, operating within local networks that feature enhanced security necessitates careful attention to data communication with external systems. The addition of an extra layer of security on the side of the data provider, such as the Comprehensive Nuclear-Test-Ban Treaty Organization's (CTBTO) Global Communication Infrastructure (GCI), introduces further complexities that must be carefully addressed to balance both functionality and protection. These challenges require solutions that maintain the integrity and reliability of data exchanges while ensuring robust security. This contribution presents the setup recently established by the Swedish National Data Centre (NDC) at the Swedish Defence Research Agency (FOI), in collaboration with CTBTO's International Data Centre (IDC), to securely receive and send waveform data in real time (SeedLink) and on demand (FDSN web services). Key components of the adapted solution include the implementation of an intermediate server located within a demilitarized zone network, the deployment of IDC's new VPN docker solution, and robust methods for transferring data received at the demilitarized zone network server to the internal, high security local network. At FOI, this setup now allows for direct access to data services that would otherwise only be reachable in a less secure network environment, as well as to the services within the GCI.

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**O4.3 Use of enabling Information Technologies** - Board: 0 / **O4.3-165**

## Rapidly Changing Metadata (RCM): a Project to Add FAIR metadata to Existing Standards

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Ground based observing networks (e.g. CTBTO/IMS, FDSN) usually have static metadata. Some observing systems have rapidly changing metadata (e.g., moving stations) difficult to include in existing formats. The RCM project enables standardized methods to include rapidly changing metadata, improving FAIRness (Findability, Accessibility, Interoperability, and Reusability) of data. Project RCM's motivation came from the EarthScope-Oceans MERMAID effort that deals with hydrophones floating in ocean currents, recording energy from seismic events. The location of MERMAID platforms can change by thousands of kilometers and is difficult to capture in the standard SEED format. In addition to location, we have identified other metadata elements that may change rapidly, including sensor (e.g., sensor type, calibration), timing (e.g., sample rate, timing corrections), orientation (e.g. sensor azimuth/dip either calculated or measured), and other rapidly changing metadata elements, if needed. The project uses structured GeoCSV files that capture rapidly changing metadata in a self-describing manner using file headers and column headers identifying key information, such as units, variable types, and parameter descriptions for related columns. It makes the data more FAIR by allowing inclusion of attributes that change rapidly in a well-documented and understandable manner. The RCM project scope and status will be discussed in this presentation.

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**O4.3 Use of enabling Information Technologies** - Board: 0 / **O4.3-565**

# A framework for developing Large Language Model (LLM) applications

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We present a framework for developing Large Language Model (LLM) applications that integrate with various data sources and systems, enabling advanced AI-driven capabilities. Our approach focuses on automating time-consuming/repetitive tasks that require knowledge work through incremental deployment of LLM applications, which can process unstructured information in a common sense manner. We utilize a Retrieval Augmented Generation (RAG) framework to incorporate external knowledge and in-context learning techniques, allowing our LLM applications to learn new skills and adapt to changing contexts. Our framework is built upon open source tools, which provide a scalable and flexible platform for developing and deploying LLM applications locally in our dedicated GPU infrastructure. We demonstrate the capabilities of our framework through various Comprehensive Nuclear-Test-Ban Treaty Organization use cases, including purpose-built AI assistants, coding assistants, and research assistants such as a paper reviewer and a plagiarism detector.

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**O4.4 International Monitoring System Sustainment into the future** - Board: 0 / **O4.4-010**

# Recent developments in advanced materials tailored for enhancing the longevity and sustainability of hydroacoustic stations

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The sustainment of hydroacoustic stations is crucial for global monitoring and the verification of nuclear test-ban compliance. These stations, operating in harsh marine environments, require advanced materials to ensure their longevity/reliability. Recent developments in superhydrophobic coatings have shown great promise in enhancing the durability and sustainability of these stations. Superhydrophobic coatings, known for their extreme water repellency, are designed through nanostructuring and chemical treatments that create a rough surface to trap air. This minimizes contact with water, reducing corrosion and wear. In hydroacoustic stations exposed to saline and corrosive underwater conditions, such coatings act as a protective barrier, preventing electrochemical reactions that lead to material degradation.
In this study, a new type of superhydrophobic nanocomposites was prepared by reinforcing a phthalonitrile resin with different amounts of surface-modified titania nanoparticles. The results from electrochemical impedance spectroscopy revealed that the neat resin and its nanocomposites offer excellent corrosion protective properties for over two years. These new kinds of superhydrophobic coatings are promising materials to be used in extremely corrosive environments. By integrating superhydrophobic coatings, the Comprehensive Nuclear-Test-Ban Treaty Organization can significantly extend the service life and performance of its hydroacoustic stations, supporting the Organization's mission for long term and sustainable global security monitoring.

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**O4.4 International Monitoring System Sustainment into the future** - Board: 0 / **O4.4-156**

# Integration of mass position monitoring and auto centering on Indonesian seismic networks

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Effective maintenance strategies and quality assurance are critical for sustaining the performance of seismic networks. The optimal mass position of seismic sensors directly impacts the quality of seismic signals, yet the diverse interfaces provided by various digitizer manufacturers complicate consistent monitoring and state of health evaluations. In Indonesia's extensive seismic network, these challenges are exacerbated by the network's geographic scale and diversity of deployed systems. This study presents a systems integration approach to optimize maintenance processes and enhance monitoring capabilities. A Web based unified dashboard aggregates mass position data from multiple digitizer interfaces, streamlining quality assurance and state of health tracking. Coupled with an integrated controller, the system enables predictive and preventative maintenance by automating mass re-centering, reducing the need for manual interventions and reactive repairs. The solution improves operational efficiency, ensures high quality seismic data, and supports optimization efforts in multi-vendor environments. By prioritizing enhanced monitoring and predictive maintenance, this approach minimizes downtime and ensures the long term reliability of seismic instruments. This

presentation will detail the development, implementation, and benefits of this integrated system, offering a blueprint for advancing maintenance strategies and optimizing seismic network operations on a global scale.

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**O4.4 International Monitoring System Sustainment into the future** - Board: 0 / **O4.4-273**

## Full Chain In-Situ Calibration of Hydroacoustic Hydrophone Stations

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Hydroacoustic hydrophone stations of the International Monitoring System (IMS) network continuously monitor the global oceans for nuclear test explosions. The stations are equipped with hydrophones in triplet configurations placed in the SOFAR channel, where the speed of sound reaches its minimum, to detect acoustic events. Acoustic signals detected by the hydrophones are conveyed to the deep-water node, which contains the electronics that convert them into digital signals, via analog cables. These signals are then transmitted to CRF through fiber-optic cables. The full-chain calibration of a hydrophone station is currently performed once, in a laboratory setting, before deployment. After deployment, the calibration is performed from the CRF up to the node section without the contribution of the analog part that contains information related to the hydrophone and the riser cable. The end to end in situ calibration of hydroacoustic stations is important for assessing the health of the full chain. Key challenges include the low frequency spectrum range and deep-ocean conditions. Since the hydrophone is the primary sensing component, full-chain calibration with active source has the potential to provide valuable information regarding the overall receiving sensitivity levels and support the assessment of the station's sustainability. The current approaches and feasibility for low frequency underwater acoustic in situ calibration will be presented.

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**Online oral session** - Board: 0 / **O4.4-458**

## Towards Predictive Maintenance Strategy Through Waveform Anomaly Detection using Unsupervised Learning

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Early stage identification of seismic station equipment problems can save unnecessary maintenance on healthy equipment, while prompting necessary maintenance on equipment at risk of failure. Performing maintenance before equipment fails can ensure data quality and avoid outages. In a previous study, we proposed an unsupervised deep autoencoder model to detect ambient data anomalies, indicating possible equipment failure. We tested this approach with the U.S. portion of the International Monitoring System (IMS) seismic arrays and successfully demonstrated its ability to detect anomalies on a monthly scale, which can prompt system maintenance before complete failure occurs. Application to other IMS arrays shows good agreement between the detection of anomalous data before unscheduled maintenance visits. This demonstrates that the model can effectively identify potential system failures at stations not included in the model training. Based on this, we are building a quality control tool that can determine if a station is behaving normally or may require maintenance. This can augment existing quality control methods to enhance the overall effectiveness of station sustainability. Here, we further extend the application of the data quality model to a worldwide network.

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**O4.4 International Monitoring System Sustainment into the future** - Board: 0 / **O4.4-885**

## Erosion and subsidence prevention at AS007 (BRDH) auxiliary seismic station for sustainable operation and maintenance

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Since 2011, Bangladesh has been hosting an International Monitoring System (IMS) auxiliary seismic station, AS7 (BRDH), in Bariadhala, Chattogram. The station is located atop a hill. Erosion of the sediments and subsidence occurred on the flanks of the hills around the seismic vault and the building. As a consequence, the floor of the building began to subside as well, fractures and cracks opened at the bottom of the walls and in the external pavement in various places, creating a potential risk for the safety of the station. To resolve the problem, Bangladesh Atomic Energy Commission and the Provisional Technical Secretariat have agreed to reinforce the station infrastructure and its surroundings. Appropriate soil stabilization techniques were conducted to protect against hill erosion and subsidence, with funding jointly provided by the European Union and Bangladesh. After critical analysis of the subsidence rate, cracks and fractures formed, building condition, surrounding environment, soil formation, drainage system, and other factors in and around the station, partial dismantling of the existing structure and subsequent renovations were carried out. In addition, the plantation of suitable trees was carried out around the station building for soil erosion resistance. Renovation work enables the station to be operated and sustained over a long period of time.

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**O4.5 On-Site Inspection Team Functionality** - Board: 0 / **O4.5-205**

# Recent strides in a 3-D aqueous fate and transport model

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ALGE is a 3-D aqueous model capable of simulating thermal and contaminant transport, including the fate of dissolved and particulate materials, along with suspended sediment. The model has been applied to quantifying cooling dissipation and providing consequence assessment for accidental releases of chemicals and radionuclides in complex ecosystems. The ALGE model is currently prepopulated for a variety of rivers, lakes, bays, and coastal estuaries across the continental United States. However, ALGE can be utilized globally for any coastal or inland body of water. New applications of ALGE include investigating anthropogenic runoff to ascertain the impact of urban heat islands in evolving ecosystems due to urbanization, and understanding how microplastics are transforming the environment across multiple scales. Coupling with hydrodynamic models, such as the Army Corps of engineers Hydrologic Modeling System (HEC-HMS), incorporates runoff and watershed estimates due to rainfall as source inputs. Other recent developments include the addition of physical processes such as coagulation of breakup and sediment, allowing for proper characterization of particulate contaminants that flow downstream. These developments illustrate the broad applications for ALGE as a robust tool for assessing emissions and pathways with relevant linkages to the nuclear fuel cycle.

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**O4.5 On-Site Inspection Team Functionality** - Board: 0 / **O4.5-276**

# Development of OSI Forward Modelling Capacity for Non-Seismic Geophysical Techniques

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An on-site inspection (OSI) foresees the use of multi-geophysical methods to investigate the presence of possible underground nuclear explosion (UNE)-relevant observables at a given site to assist in identifying any possible violator of the Comprehensive Nuclear-Test-Ban Treaty. We present the results of numerical simulations obtained by means of Python functions based on the Simpeg libraries, calculating the 3-D forward response of UNE-observables for non-seismic methods such as magnetic, gravimetric, frequency/time-domain electromagnetic methods and electrical resistivity tomography. We have identified five main scenarios based on realistic possible UNE emplacements: a buried cavity with eventual addition of alteration shells and a chimney with and without a metallic borehole casing; and a horizontal emplacement including a tunnel with metallic rails and doors, alteration shells, a chimney, an apical void, and changing topography. For each scenario, simulations have been carried out varying the observables' geometric and physical parameters. Our results provide a portfolio of UNE non-seismic anomalies that can greatly aid the choice of the OSI technique to apply and the design of the surveys. Therefore, the results are of extreme importance for the further development of the OSI training programme for surrogate inspectors as well as for the development of the OSI equipment list.

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## An ITF framework for condensed OSI exercises

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The inspection team functionality (ITF) is the conceptual framework that guides the inspection team during a Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) on-site inspection (OSI). ITF provides a structured thinking space, which limits the impact of cognitive bias and noise on the decisions taken by the inspection team. With that purpose, ITF acts as a regulatory system that slows down the human impulse to quickly reach conclusions based on incomplete information and expert bias. The rigor and safety provided, however, collides with the artificial time pressure imposed on the inspection team during abridged OSI exercises. This has led to the implementation of ad-hoc shortcuts that inadvertently erode the protections provided by the ITF. In this paper we present an approach to be used during time condensed OSI field exercises. This approach emphasises the importance of the information collected, the foundations of objective decision making, and the resourcing of field missions through the search logic. Time compression can also be accommodated through modification to meeting formats and template schedules for the implementation of the ITF cycle over several days. We have also developed guidance on exercise and scenario planning to protect the quality of inspection and decision making processes under the time pressure often imposed when implementing ITF.

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**O4.5 On-Site Inspection Team Functionality** - Board: 0 / **O4.5-687**

## Realistic and achievable sample representativeness for the environmental sampling during an OSI

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During an on-site inspection (OSI), the collection and analysis of environmental samples in the inspected area is allowed by the Treaty and its Protocol. The procedures for the selection of the samples

and their collection are described in the draft Operational Manual and in the related OSI documentation. A field mission must be carefully planned and, based on its objectives, the inspectors should establish the number of samples to collect to have an accurate representation of the area. The analysis of the representativeness of a sample is common in several disciplines: i.e, in pedology studies, in sociology, in forensic science, different methods are implemented to collect information on the investigated event. The minimum number of samples is based on several crucial factors, including the dimension of the site, the sample feature proportion, the phenomena associated with the dispersion, and the level of interest in the specific zone. Different statistical methods are applicable to determine a priori the number of samples for a specific trial, and we have compared some of them to find out the best suited for the OSI. We have compared different sampling techniques, as well as the statistical approaches to assess the achievable representativeness of environmental sampling during an OSI.

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## Harnessing Satellite Imagery Analysis for CTBT Verification

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Recent advancements in commercial satellite technology have emerged as powerful tools to support Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification efforts. This presentation explores the potential of high resolution satellite imagery to enhance monitoring and verification capabilities. It delves into recent analyses of activities at both current and former nuclear test sites, as well as ongoing evaluations on how satellite imagery can best be utilized to verify compliance with testing moratoria. Key applications include detecting visible indicators of nuclear testing activities, such as ground disturbances, infrastructure changes, and anomalous activity patterns at suspected test sites. Additionally, advanced methodologies, including synthetic aperture radar, multispectral imaging, and change detection analysis, enable the identification of subtle signs of preparatory or post-test activities that might otherwise go unnoticed. Satellite imagery offers timely, cost-effective, and non-intrusive data, complementing the International Monitoring System and on-site inspection capabilities. By leveraging the rapid evolution of commercial space technologies, CTBT verification can gain enhanced situational awareness, fostering global confidence in compliance with the Treaty.

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**O5.1 Synergies with Global Challenges** - Board: 0 / **O5.1-095**

## Wandering albatrosses ride infrasonic waves over large geographic scales

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Predicting and responding to changing environmental conditions is an essential part of making optimal decisions about movement. Over small spatial scales such decisions may be guided by short-range cues, but it can be unclear what cues underlie movement at scales exceeding 1000s of km. Infrasound could form such a cue. In marine habitats, infrasound is largely generated by non-linear wave interactions that are associated with storms. For ocean-faring species, infrasound sensitivity could therefore help animals to either avoid these weather fronts, or if such conditions are favourable to movement, move towards them. Yet despite its potential utility as a cue, behavioural responses to infrasound have been investigated in very few species. We tested whether one of the furthest ranging seabirds, the wandering albatross, shows movement trajectories consistent with responsiveness to infrasound. We used high-resolution GPS data collected from 89 albatrosses breeding on Crozet Island, in combination with modelled infrasound maps, to show that albatrosses move towards areas containing higher infrasound levels and propose that this might allow them to anticipate conditions optimal for flight at long distances. This provides the first evidence for infrasound responsiveness in a free-ranging bird, broadening our understanding of how animals perceive and navigate vast featureless habitats.

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# Seasonality of sea ice extent and microbarom amplitude at high-latitude IMS infrasound stations

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The International Monitoring System (IMS) infrasound network's ability to detect atmospheric nuclear detonations is limited by a combination of wind-noise, anthropogenic sources, and the microbarom, the constant and globally ubiquitous infrasonic noise driven by oceanic waves. The presence of seasonal weather conditions may increase the strength of the microbarom, further increasing background noise at IMS stations. The microbarom may also strengthen due to seasonal variation in sea ice extent at high latitudes. In several studies, sea ice has been shown to inhibit the generation of the microseism, the seismic noise equivalent of the microbarom. Here we analyze ten years of acoustic data collected at six high-latitude IMS infrasound stations alongside hemispheric sea ice extent. We find that microbarom strength varies smoothly with the seasons by a factor of 2-5 but is out of phase with hemispheric sea ice extent. At each station, the maximum and minimum microbarom strength occurs 2-4 months before the maximum and minimum sea ice extent, respectively. We do not observe a clear relationship indicative that microbarom strength is diminished by hemispheric-scale sea ice. Instead, we now consider that other hemispheric-scale seasonal variations over the world's oceans will outweigh the effects of sea ice extent on the strength of the microbarom.

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## Verification and Modelling of Tsunami Arrival Time and Wave Height Along Thailand's Andaman Sea Coast Using an Enhanced TOAST

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After the Sumatra-Andaman earthquake, leading to a tsunami devastating Thailand's west coast, concerns were raised about the effects on infrastructure and human life. This study aims to model Tsunami Arrival Times and Wave Heights along the Andaman Sea Coast of Thailand using the TOAST (Tsunami Observation and Simulation Terminal) module integrated into the SeisComP software. The default bathymetry resolution was modified from 3.7 km to 0.46 km, and the impacted area was set to more detail at the subdistrict level to improve the accuracy of hazard assessments. The 2004 Indian Ocean Tsunami simulations and actual tidal gauge data were compared to evaluate the accuracy of the improved TOAST model. There was no significant difference in the first tsunami wave arrival. However, the maximum wave arrival time was close to the actual data at the Kuraburi tide gauge station, which was 9 minutes early, and 28 minutes late at Taphao Noi tide gauge station. Simulations along the Sumatra-Andaman subduction zone identified Lam Kaen Subdistrict as the first impacted area and Thung Maphrao Subdistrict as having the highest wave height. Thus, the adjusted TOAST can inform the public about tsunami arrival times on Thailand's west coast.

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## The Volcanic Information System: Long-Range Infrasound Monitoring of Volcanic Eruptions

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Explosive volcanic eruptions produce large amount of infrasound (<20 Hz), which can propagate over hundreds to thousands of kilometers in the atmosphere. These eruptions also inject large amounts of ash in the atmosphere, posing a direct threat to commercial flights and the population under the ash plume trajectory.

The Volcanic Information System (VIS) was developed within the Atmospheric dynamics Research InfraStructure in Europe (ARISE) project, in collaboration with the Toulouse Volcanic Ash Advisory Center (VAAC). The VIS is a prototype monitoring system that uses long-range (>250 km) infrasound detections to remotely detect and notify explosive eruptions.

The VIS was designed to use observations from the global International Monitoring System (IMS) infrasound network, but also non-IMS infrasound arrays. To detect an eruption, the VIS relies on the Infrasound Parameter (IP), which accounts for propagation effects, detection persistency and amplitude.

In the current study, we statistically assess the reliability of the VIS to detect, locate and raise automatic notifications for the VAACs, considering global datasets derived from all available IMS stations (2003-present). We also present the current web-based service prototype and the road map to make it available to the public.

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**O5.1 Synergies with Global Challenges** - Board: 0 / **O5.1-803**

# Monitoring whale populations from acoustic data over large temporal and spatial scales

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Research using acoustic recordings to estimate animal population sizes is being applied increasingly frequently to both marine and terrestrial species. Here, data from the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO) International Monitoring System (IMS) hydroacoustic stations have been used to monitor baleen whales. For example, several baleen whale species have been recorded at Diego Garcia in the Indian Ocean including blue (*Balaenoptera musculus*), fin (*B. physalus*) and suspected Omura's whales (*B. omurai*). The CTBTO IMS has been collecting data at Diego Garcia across multiple decades and the placement of the hydrophones in the deep sound channel enables long-range detection of whale calls. By covering both large spatial and temporal scales, the CTBTO IMS is a valuable dataset for the potential assessment of trends in population size and distribution of several baleen whale species. To estimate whale population densities from CTBTO IMS instruments, simulation-based statistical methods have been implemented to estimate detection probability, a key parameter required for density estimation. The simulations require several data inputs including bearings to target whale calls, transmission loss data, noise level measurements and assumed source levels of the calls. Results from a case study focusing on Sri Lankan blue whale calls will be presented.

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**O5.2 Regional Empowerment** - Board: 0 / **O5.2-018**

## NDC in a box analysis of the 17-18 August 2024 Kamchatka seismo-volcanic events: opportunities for integration of the CTBTO IMS system into Kenya's preparedness for concomitant geohazards

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On 17 August 2024, an mb6.0 earthquake at a depth of 29 km occurred approximately 102 km south-east of Petropavlovsk-Kamchatsky, Russian Federation. The earthquake triggered the eruption of the Shiveluch volcano the following day, producing a 9000-meter ash plume. Using his Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) National Data Centre NDC training from 5 to 16 August 2024 in Nairobi, Kenya, the author accessed waveform and infrasound data from the CTBTO's Secure Web Portal SEL2/3 database. Using the CTBTO's NDC in a box suite, he analysed seismic data from Kamchatka peninsula stations using GeoTool and infrasound data from I44RU station using DTK-GPMCC. Results indicate that the earthquake occurred near Severneye (53.58°N, 158.42°E) about 390 km south of the Shiveluch volcano, highlighting the potential for large local seismic events to trigger coupled volcanicity. Kenya's Rift Valley has dormant volcanoes like Central and South Island within Lake Turkana, a tectonic zone with instrumental M6.0–6.5 earthquakes. While the risk of actual volcanic eruptions may be low, significant earthquakes in the region could trigger non-eruptive geohazards such as volcanic landslides, leading to seiches. Kenya's preparedness for such natural disasters could benefit greatly from the CTBTO International Monitoring System seismic and infrasound network, leveraging partnerships to improve geohazards monitoring and preparedness capabilities.

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## Application of the Capacity Building System (CBS) at National Data Center (NDC) of Bangladesh

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) recently installed a capacity building system (CBS) at the National Data Centre (NDC) in Bangladesh. The CBS is designed to help technical staff use the CTBTO International Monitoring System (IMS) data and International

Data Centre (IDC) products more efficiently and accurately. Through this new CBS that comes with some analysis programs, it has made our work much easier in analysis, getting data from other surrounding countries and providing sufficient knowledge and assistance for edifice NDC and/or improving capabilities. Different products of the IDC and Regional Seismic Travel Time (RSTT) data from NDC-BD are being utilized for natural earthquake monitoring as well as subsurface geological information. During the last few years, seismic data from the IDC through VSAT communication have been continuously monitored for natural earthquakes generating in and around Bangladesh and also for monitoring any usual or unusual seismic activities. The significance of setting up the NDC is enabling us to constantly monitor, manage and coordinate both natural and human-made seismic activities in the country and around the globe, which could be useful to improve the disaster preparedness systems of the country. The NDC makes the data available to its stakeholders and reports on disaster-related information to government agencies.

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## Leveraging on the Support CTBTO CBS Offers; Lessons Learnt

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The international community, mindful of the severe impact of nuclear test explosions, agreed to positive measures to reduce and prevent the further use of these weapons of mass destruction. Hence, the adoption of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) by the United Nations General Assembly in 1996 was an essential step in the field of nuclear disarmament and non-proliferation for peace and security. Under the treaty, to support States Signatories to carry out their verification responsibilities, the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) provides them with services and technical assistance. Through the organization of conferences, training, meetings and workshops, it offers States Signatories opportunities to participate and contribute to the implementation of the global verification monitoring. Programmes such as the National Data Centre workshop series, which brings to bear the technical assistance opportunities that the CTBTO provides. Through this forum, the information about the availability of the technical support programme under the capacity building system project for GCI-III/VSAT equipment was heard. Resulting in the request and receipt of GCI-III/VSAT equipment by the Republic of Ghana in July 2021 from the CTBTO. This study, therefore, seeks to demonstrate the opportunity to leverage the available services and technical assistance that CTBTO provides under the Treaty.

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## Strengthening National Data Centre Through Regional Empowerment: A story of Malaysia

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Malaysia signed the Comprehensive Nuclear-Test-Ban Treaty (CTBT) in 1998 and ratified it in 2008. To demonstrate its commitment, Malaysia established the National Data Centre (My-NDC) to maximize its CTBT membership. Initially, with only three analysts, My-NDC has grown to 20 analysts from diverse backgrounds. A key challenge is the effective training of these analysts to ensure optimal operation of the center. To enhance the capacity of My-NDC, Malaysia conducted a gap analysis to identify strategies for its development. One strategy is to form partnerships with advanced States Signatories, addressing technical expertise, national capabilities and resource constraints. Based on the gap analysis, Malaysia aims to connect with regional countries proficient in CTBT technology. In line with this, My-NDC has partnered with Geoscience Australia and the Australian Safeguards and Non-Proliferation Office (ASNO), which aids in strengthening knowledge of My-NDC of waveform technology and radionuclide analysis. Initiatives such as training programmes and scientific visits have been launched to support the role of My-NDC in CTBT implementation. These efforts align with the broader vision of Malaysia of integrating CTBT-related activities into national policies and extending collaboration to other SEAPFE countries, fostering regional nuclear test monitoring and contributing to sustainable development and public welfare.

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# Recent Seismic Activity & Improvements with Earthquake Monitoring in Jamaica

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Jamaica is located in a seismically active zone in the northern Caribbean where historical events including the 1692 Port Royal and 1907 Kingston earthquakes resulted in significant loss. The 2023 magnitude 5.6 earthquake and 2024 magnitude 5.2 earthquake highlighted the continued risk from significant ground shaking and the propagation of seismic hazards. Over the last two years, the Earthquake Unit (NDC-JM) in Jamaica located 653 local and 285 near region earthquakes. Additionally, the Jamaica Seismic Network recorded over 80 possible explosions most likely related to local mining and quarrying activities. Recent improvements to the seismic network include the addition of 11 new low cost seismographs along with station enhancements including upgraded power systems at several broadband sites. The incorporation of these new sensors contributes to improved event detection and enhanced data quality for the national seismic monitoring programme. Results from waveform analysis show a significant decrease in RMS location errors and provides a solid foundation for earthquake catalogue work including refining the 1-D velocity model and for event relocation. The NDC-JM will continue to build out the seismograph network, incorporate regional

data and CTBTO's IDC data to fill existing gaps and improve the data quality for seismic monitoring and research.

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**O5.3 Outreach** - Board: 0 / **O5.3-011**

## Leveraging social media to elevate awareness of nuclear tests vs natural earthquakes among Indonesia's diverse communities

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Public awareness of the differences between nuclear explosions and natural earthquakes is crucial for national safety, especially in Indonesia, a country renowned for its seismic activity and demographic diversity. According to the BMKG Indonesia, this country experienced approximately 10 789 earthquakes in 2023. This frequency poses a unique challenge for communicating the distinctions between these seismic events and potential nuclear tests, which is a central duty of the CTBTO. As the nation seeks to improve its preparedness for nuclear threats, effective communication becomes essential. The rise of social media usage across Indonesia has created new opportunities for public engagement and information dissemination. This study aims to develop a comprehensive understanding of how social media can be leveraged to enhance awareness of nuclear testing among Indonesia's diverse populations. Surveys will be conducted through social media, targeting individuals aged 15 to 60 years to examine the demographics of respondents while assessing their understanding of nuclear test and earthquake preparedness. The survey will seek insights into participants' knowledge of nuclear test, prior related education, preferred sources of information and their concern about nuclear testing and earthquakes. This research presents findings that will guide strategic efforts to disseminate awareness about nuclear testing in Indonesia.

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**Online oral session** - Board: 0 / **O5.3-360**

## Tech for Tolerance: Using Gamification to Drive Youth Engagement in the Nuclear-Test-Ban Treaty

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This paper explores how gamification can enhance youth engagement in CTBT advocacy and verification. By bridging barriers, gamification fosters participation in test ban monitoring at the intersection of technology, policy and advocacy. CTBTO's mission depends on global awareness,

technical expertise and diplomatic engagement — yet youth involvement remains limited due to technical complexity and access challenges. This research examines how serious games, AI-driven simulations and blockchain-based verification can address these gaps, equipping youth with tools to monitor and advocate for nonproliferation. Key focus would be integrating gamification into IMS applications. AI-driven anomaly detection challenges could train youth to interpret datasets, distinguish nuclear tests from seismic events and apply ATM to track radionuclide dispersion. Gamified exercises could simulate verification tasks, enabling users to identify clandestine tests. AR-based OSI scenarios would allow players to deploy sensors, analyze isotopes and conduct forensic radiochemistry, mirroring CTBTO methodologies.
This paper analyzes the potential of gamification techniques like Global Nuclear Test-Risk Map, AI-powered Crisis Simulation and Radiation Propagation Simulator. Inspired by NUKEMAP and NATO's Locked Shields, it envisions a gamified CTBT platform integrating historical test data into scenario-based missions. AI-driven learning ensures scalable participation, fostering a technically-proficient generation committed to nuclear verification and policy advocacy.

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## A Decade of Teaching Nuclear Weapons and Arms Control: Lessons for the Future

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Our undergraduate course titled "Nuclear Weapons and Arms Control" was created at the University of British Columbia (UBC) in 2014. The course has proven to be a very successful awareness and outreach effort and a model for future nuclear weapons education. From 2014 to 2024, the nearly 1000 students enrolled in the course have engaged in the science and politics of nuclear weapons and arms control and written major research projects on the CTBT. Central to the course model is the continuing multidisciplinary teaching collaboration between the Departments of Political Science (Dr. Allen Sens) and Electrical and Computer Engineering (Dr. Matt Yedlin). The course is unique as it enrolls both Arts and Engineering students working together in groups in a "flipped classroom" environment. We will present the course design and learning outcomes and evaluate student engagement using data from YouTube and student surveys. We propose the development of a version of the course that is accessible to the public and takes advantage of the potential of Generative AI. Based on our decade of teaching experience, we would like to collaborate with the CTBTO and universities interested in creating satellite versions of our course.

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## Expanding the CTBTO's Role as a Public Communicator in Addressing Disinformation Post-Entry into Force

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The CTBTO is renowned for its success in building up the CTBT verification regime, collecting and analyzing data, and sharing timely information with state signatories to monitor compliance with the Treaty. Post-entry into force (EIF), the CTBTO could broaden its role as a public communicator to address disinformation surrounding allegations of nuclear testing. A notable example of this potential was PTS's handling of two high-profile seismic events on 5 October 2024 in Iran. Amid loud speculation that these events were covert nuclear tests, PTS dispelled the disinformation and de-escalated tensions, demonstrating the organization's ability to counter misinformation through science-based transparency as a trusted public communicator. This paper identifies the political and legal hurdles that may impede the organization's ability to assume such a role post-EIF within the Treaty framework and proposes strategies to overcome them. Beyond, a dedicated team, specializing in disinformation response and science communication, comprising experts from OES, IMS and IDC with broad geographic representation is recommended. Expanding this public-facing role would position the CTBTO as a trusted arbiter of truth in the information war era, enhancing the verification regime's credibility and underscoring the value of multilateralism and science-driven diplomacy in addressing global security threats.

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**Opening / OP**

## Online Opening

Stay tuned for the Online Opening that will commence at 13:15 CET!

Welcome message by the SnT2025 Project Executive
Practical information and tips by the SnT2025 Coordinator

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**P1.1 The Atmosphere and its Dynamics** - Board: 1 / **P1.1-022**

## Structure of the atmosphere in the form of a 'head of cabbage' from acoustic sounding data

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The results of theoretical and experimental studies of the fine-scale layered structure (anisotropic turbulence) of the middle atmosphere (20-140 km) using the acoustic method are presented. Based on the developed model, the possibility of formation of a fine-scale layered structure of the middle atmosphere by internal gravity waves from meteorological fronts is shown. Vertical and horizontal spectra of anisotropic inhomogeneities are presented. The vertical profiles of anisotropic inhomogeneities are reconstructed from the parameters of infrasound waves generated by explosions and volcanic eruptions. A new method of signal decomposition into separate pulses by the pattern recognition method was proposed. It was shown that the fine structure of the middle atmosphere can be stable for significant time intervals throughout the entire thickness of the middle atmosphere. At the same time, the large scale anisotropic structures themselves can be schematically represented as a superposition of separate 'pancakes' with different vertical temperature and wind gradients. This structure in the form of a 'head of cabbage' is characteristic of the whole atmosphere regardless of its spatial distribution and can be stable in general and in details over appreciable time intervals .

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**P1.1 The Atmosphere and its Dynamics** - Board: 2 / **P1.1-035**

# Air quality impact on the sampling possibilities of the International Monitoring System radionuclide particulate stations

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The International Monitoring System particulate radionuclide station air sampler is a specialized device designed to detect and measure radioactive particles in the atmosphere. It forms part of a global network tasked with monitoring adherence to the Comprehensive Nuclear-Test-Ban Treaty. By continuously sampling the air, these stations play a crucial role in detecting unauthorized nuclear activities, thereby enhancing global security and safety. However, poor air quality can diminish sampling efficiency by affecting the airflow rate through the filter, consequently impacting the volume of the analysed air and detection sensitivity. Elevated levels of dust, smoke, or other particles accelerate filter clogging, reducing the samplers performance and potentially obscuring radionuclides. Additionally, weather conditions such as heavy rain, strong winds, and humidity can influence radionuclide dispersion and concentration, complicating detection efforts. This study examines the number of particulate station sampler's impacted by the reduced total sampling volume due to filter clogging. The data is analysed alongside variations in 7 Be concentrations and seasonal atmospheric transport models (where applicable).

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**P1.1 The Atmosphere and its Dynamics** - Board: 3 / **P1.1-115**

## The influence of acoustic and internal gravity waves from atmospheric storms on the parameters of the upper atmosphere

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Numerical modeling of the propagation of atmospheric waves before atmospheric storms in the Moscow region was performed. A three-dimensional version of the high resolution nonlinear numerical model AtmoSym was used for the simulation. Experimental observations from a network of four microbarographs located in the Moscow region were taken as a source of disturbances. Wave characteristics of disturbances in the upper atmosphere caused by the generation of acoustic and internal gravity waves from atmospheric storms was obtained. Numerical calculations showed the formation of local heating areas form in the upper layers of the atmosphere, which affects wave propagation.

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**P1.1 The Atmosphere and its Dynamics** - Board: 4 / **P1.1-183**

## Combined loss of coherence and network covering methods to improve I17CI detections by adding dummy sensors

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In the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), Côte d'Ivoire benefits from two primary stations: seismic (PS15) and infrasound (I17CI) respectively for monitoring underground and airborne nuclear tests. Upgrading the infrasound station I17CI from four to more sensors is part of the CTBTO's medium term objectives. Thus, this research project is part of the preliminary studies prior to the implementation of this major CTBTO project. We combined coherence and network covering methods to take part of the similarity of signals across all sensors and also network sensitivity to event detection by adding dummy sensors.

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**P1.1 The Atmosphere and its Dynamics** - Board: 5 / **P1.1-227**

# Analysing bolide shock source and propagation variability through a case study

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In theory, infrasound signals generated by bolides offer a window into understanding source properties, such as shock altitude and energy. However, to accurately leverage these signals, both ground truth and accurate atmospheric specifications are essential, as dynamic atmospheric variations over minutes to hours can affect signal viability, and complex propagation paths may lead to unexpected detections or missed signals. A noteworthy example is the 23 July 2008 bolide over Tajikistan, detected at two Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO) International Monitoring System network stations (1500-2100 km from the source). Surprisingly, propagation models using realistic atmospheric profiles predicted signal arrival at one of the stations, yet detection occurred at both. This anomaly was likely caused by acoustic energy guided within a leaky stratospheric duct—a phenomenon only recently confirmed by high-altitude balloon infrasound experiments. The primary shock originated from a spherical blast due to the main fragmentation event of the bolide. This study demonstrates the capability of infrasound to characterize bolide events, supporting advancements in CTBTO's atmospheric event detection and interpretation.
SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

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**P1.1 The Atmosphere and its Dynamics** - Board: 6 / **P1.1-228**

# Investigation of anomalously fast infrasound phases from global bolide events

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Anomalously fast infrasound phases, with unexpectedly high celerities, present a challenge for accurate modeling and detection of atmospheric events over long distances. While fast arrivals are typically confined to short-range propagation (within 300 km) where boundary layer effects are dominant, recent observations reveal celerities exceeding 330 m/s at ranges spanning thousands of kilometers. To understand the cause of these early arrivals, we analyze a dataset of 172 bolide events, using information from United States Government sensors in the NASA JPL CNEOS database and global infrasound detections reported in the literature. Each event includes detailed infrasound parameters, arrival times, and celerities, allowing us to systematically compare observed speeds with theoretical predictions across various atmospheric waveguides. Our findings suggest that these fast arrivals may result from specific propagation effects, such as narrow stratospheric ducts or favorable downwind conditions that enhance signal speed over long distances. By incorporating bolide-specific parameters, this study aims to advance the infrasound monitoring capabilities of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization, improving

detection and characterization of both natural and anthropogenic atmospheric events on a global scale.
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**P1.1 The Atmosphere and its Dynamics** - Board: 8 / **P1.1-363**

## Studying infrasound propagation in the middle atmosphere with the upper atmosphere model UA-ICON: parameterization and characterization of gravity waves

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Infrasound signals are used to monitor various anthropogenic and natural sources. To determine precise source locations and energy, an accurate model of wind and temperature from the surface up to the lower thermosphere is necessary, hence operational NWP products are of great importance for routine infrasound monitoring activities. However, many of these models focus on tropospheric conditions, and the middle and upper atmosphere, where the relevant infrasound waveguides for long range propagation are found, is not well represented. UA-ICON is an upper atmosphere version of the ICOsahedral non-hydrostatic weather and climate model (ICON) that provides modelled atmospheric parameters up to the lower thermosphere. In addition, small scale perturbations, most notably gravity waves, have a large impact on both background wind and temperature patterns through energy deposition and drag, hence indirectly on infrasound propagation. They also directly impact infrasound by forming small scale atmospheric heterogeneities causing partial reflections of acoustic waves. Therefore, the 3-D version of the transient Multi-Scale Gravity Wave Model (MS-GWaM) was used within UA-ICON to produce realistic background conditions, and predict global gravity wave activity. We will present the methodology used to generate the wind and temperature gravity wave perturbation profiles, and analysis of infrasound propagation using these gravity wave realizations.

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**P1.1 The Atmosphere and its Dynamics** - Board: 9 / **P1.1-422**

## Assessing Plume Detectability Using Multiscale Atmospheric Transport Modeling

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Multiscale atmospheric transport models (ATM) resolve mesoscale meteorology, such as frontal passages, and microscale meteorology near-source, which is often strongly influenced by complex terrain and heterogeneity of the land surface. The ability of material collection stations to detect passing plumes can be strongly influenced by local variations in atmospheric flow, particularly nearby the source and detector, which motivates the development and use of multiscale ATM. Resolving the diverse meteorological phenomena of interest within a multiscale simulation requires a highly capable model, significant computational resources, and detailed knowledge of both the local and synoptic conditions. Here, we discuss lessons learned from multiscale transport and dispersion simulations executed with the Weather Research and Forecasting (WRF) model and a young model undergoing active development, the Energy Research and Forecasting (ERF) model. ERF is a highly efficient and scalable atmospheric model designed to take advantage of the latest supercomputing resources with hybrid (CPU and GPU) architectures that enables fast-running multiscale simulations approaching operational timescales. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC. This is abstract LLNL-ABS-871294.

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**P1.1 The Atmosphere and its Dynamics** - Board: 10 / **P1.1-557**

# What can we learn from a comparison of European Centre for Medium-Range Weather Forecasts and National Centers for Environmental Prediction-driven source-receptor sensitivity fields?

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One of important challenges the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) has been facing is to put an error bar on its atmospheric transport modelling (ATM) simulations. A well-established approach to address this question by the meteorological community is to run, for a given date, multiple simulations. These simulations constitute an ensemble, whose instances, or members, differ in such a way that the differences are representative of underlying meteorological uncertainty. Awaiting implementation of such an ensemble-based ATM system at the CTBTO, we propose to investigate a simple initial comparison. In fact, for many years, the CTBTO has been producing two instances of source-receptor sensitivity (SRS) fields using two sources of input meteorological data, namely, the European Centre for Medium-Range Weather Forecasts and the National Centers for Environmental Prediction. In this presentation we look into differences between these two instances of SRS fields in view of assessment of uncertainty in the ATM but also in our future derived products, essentially background characterization and probabilistic radionuclide source location.

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**Online e-Poster Session 1** - Board: 0 / **P1.1-669**

## Numerical simulation for 3-D infrasound propagation in shadow zone using a one-way approach

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During infrasound propagation in the atmosphere, shadow zones can be induced by the temperature and/or wind speed gradients, the ground surface or the source geometry. Although commonly used to simulate the atmospheric infrasound propagation at large scales and three-dimensional domains, acoustic rays method is not able to simulate the propagation where the geometrical approximation is not valid. An advanced numerical method is then necessary to simulate the infrasound propagation resulting from diffraction effects in shadow zones. We present FLHOWARD3D, a numerical model based on a one-way approximation of sound propagation and able to deal with simplified diffraction configurations in the presence of atmospheric heterogeneities. We propose a strategy based on domain splitting to take into account the diffraction effect in the shadow zone. Analytical and numerical test cases on various configurations have been implemented to valid the accuracy and to assess the robustness of the method.

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**P1.1 The Atmosphere and its Dynamics** - Board: 12 / **P1.1-709**

## Estimating gravity waves at source levels using long range infrasound waveforms

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The propagation of infrasound through the atmosphere is highly sensitive to small scale disturbances that can significantly influence waveforms. Among these, gravity waves play a critical role and are typically parameterized in General Circulation Models (GCMs). This study investigates the performance of long range infrasound modeling in reconstructing non-orographic gravity waves fields. We analyse signals recorded at an infrasound station 300 km from controlled explosions at Hukkakero, Finland, during late summers from 2014 to 2017. Using the ERA5 data set from the European Centre for Medium-Range Weather Forecasts, combined with a gravity waves multiwave scheme, we derive gravity waves fields in the lower stratosphere. Coarse-grained, column based atmospheric variables are employed to capture day to day gravity waves variability. Full wave acoustic modeling is performed using a normal mode code developed at the Commissariat à l'énergie atomique et aux énergies alternatives. Our findings are twofold. First, we demonstrate the ability to reconstruct the influence of gravity waves on infrasound waveforms using acoustic full wave modeling. Second, we show that infrasound waveforms can be used to infer and calibrate gravity waves characteristics at their source levels in the troposphere. The calibrated gravity waves model can, in turn, be applied

to solve the inverse problem of estimating the yield of explosions, with significant improvements in terms of accuracy and reliability.

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**P1.1 The Atmosphere and its Dynamics** - Board: 13 / **P1.1-749**

## Modeling the characteristics of infrasound signals as detected from a balloon platform: Earth and Venus applications

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The Strateole2 campaign deployed superpressure balloons for several weeks in the southern stratosphere. On 15 January 2022, their pressure sensors detected infrasound signals (0.01 to 1 Hz) from the major eruption of the Hunga Tonga Hunga Ha'apai (HTHH) volcano. These signals present differences in amplitude and frequency content compared to recording of ground International Monitoring System stations. Using HTHH as a case study, we apply ray-tracing and normal mode modeling techniques, coupled with ERA5 atmospheric models, to understand the particularities of the infrasound wavefield at these elevated platforms. We also propose to generalize these results to different seasons and geographical source-receiver location combinations. A key objective for our future work is to apply such frameworks to assess the possibilities for balloon based seismoacoustic probing on Venus.

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**P1.1 The Atmosphere and its Dynamics** - Board: 14 / **P1.1-794**

## Relation between rainfall variability and signals characteristics of infrasound events during the dry season in the central highland region of Madagascar

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Infrasound is one of four technologies dedicated to monitor nuclear explosions. It is used as well to study other issues for the benefit of science or to improve human life. Nowadays, rainfall variability is a widely discussed topic due to climate change. This work probes the relationship between

rainfall variability and the characteristics of infrasound signals recorded during the dry season in the central highland region of Madagascar. The analysis of rainfall patterns uses precipitation data and infrasound bulletins from 2003 to 2024. To obtain characteristics (azimuth, frequency contents, amplitude) of infrasound events. Infrasound data are processed by DTKPMCC. The results provide new perceptions into how infrasound behavior during the dry season correlates with rainfall variability. Among all infrasound events analysed, which serves as the most reliable indicator of rainfall variability?

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**P1.1 The Atmosphere and its Dynamics** - Board: 15 / **P1.1-867**

## Optimization of Selection Methods and Localization of Infrasound Sources for Solving Problems in the Monitoring of the Comprehensive Nuclear-Test-Ban Treaty

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A method for network selection and localization of global infrasound sources based on propagation velocities and azimuth deviations of infrasound signal arrivals at the infrasound stations of the International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) is developed. The method uses a network likelihood ratio approach, incorporating the Revised Event Bulletin statistics, as well as an algorithm for checking the adequacy of applying models of high altitude jet streams. To eliminate false signals that fall within the specified azimuth deviations and velocity ranges at each individual station, it is necessary to perform not only station selection but also network selection. For a large number of events from the Revised Event Bulletin, histograms of azimuth deviations and changes in signal velocities are constructed, taking into account corrections for altitude jet streams. The likelihood ratio is defined as the ratio of probabilities for true and false sources. The network likelihood ratio is compared against a threshold determined using the Monte Carlo method. Signals from a real source that exceed this network selection threshold are considered true.

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**P1.2 The Solid Earth and its Structure** - Board: 1 / **P1.2-008**

## Calibration of the local magnitude scale (M_L) for eastern Cuba

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In this study, we developed a local magnitude scale for the southeastern region of Cuba—the part of the island exposed to the greatest seismic hazard due to its proximity to the Oriente fault system. From the 2011–2021 Cuban catalog, 7750 earthquakes with ML > 2 were selected, distributed in the region 19°–22° N, 73°–79° W, and recorded by at least four seismic stations within 500 km of the hypocentre. The resulting input data set includes 33 916 amplitude measurements of the horizontal components. We set up the whole linear regression analysis procedure to obtain the formula for the local magnitude in the International Association of Seismology and Physics of the Earth's Interior form. In a three-step procedure, we removed the outliers; searched for the parameters n, K, and Si that minimize the unbiased sample standard deviation of the residuals; and set the anchor point for the parameter C. Thus, the new formula for the local magnitude ML is defined as follows: M_L=log_10(A)+1.000 log_10(R)+0.003R-1.963, in which A is the peak amplitude in nanometers simulated with a Wood–Anderson sensor and R is the hypocentral distance in kilometers. We also calculated the station correction factors S for each station included in the analysis

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**P1.2 The Solid Earth and its Structure** - Board: 2 / **P1.2-032**

# Improving the Crustal and Upper Mantle Velocity Model and Seismic Event Location Accuracy in Jordan through Integrated Analysis of Local, International Monitoring System and Non-International Monitoring System Data Using the Regional Seismic Travel Time Model

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This poster aims to show the result and method of a study to improve the understanding of Jordan's crustal and upper mantle structure and enhance the local model velocity by integrating seismic data from local Jordanian stations, International Monitoring System (IMS) stations, and non-IMS stations. Building on my previous research titled "Integrate Data from IMS and Non-IMS Stations…" the focus is on refining local and regional velocity models. Using the Regional Seismic Travel Time (RSTT) model provided by NDC in a box software for event location to re-evaluated using multiple velocity models(z. El-Isa 1987)(IASPI) for selected seismic events from the SEL3 and Revised Event Bulletin. Integrating data from Jordan's, IMS, and non-IMS stations with advanced travel time calculations provided by RSTT aims to improve the precision of seismic event localization and local velocity model. This poster will highlight the improvements in seismic event location accuracy and the refinement of the local velocity model. The expected outcomes will significantly enhance seismic monitoring capabilities in the region, contributing valuable insights for seismic hazard assessment and improving the reliability of monitoring and verification processes for Jordan and surrounding. Additionally, this study will contribute to advancing the objectives of the Comprehensive Nuclear-Test-Ban Treaty Organization, supporting the implementation of the Comprehensive Nuclear-Test-Ban Treaty and reinforcing global peace and security.

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**P1.2 The Solid Earth and its Structure** - Board: 46 / **P1.2-044**

## A computer code for calculating velocity structure parameters using Rayleigh wave phase velocity dispersion data

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We developed a computer code to derive a crust and upper mantle velocity structure for southwest Iran (Firuzabad region) in the central Zagros by an application of the two events, single station method of Rayleigh wave phase velocity dispersion analysis. Three sets of digital recordings of large earthquakes in the Firuzabad region in 1994 and 1995 made at the Iranian Long Period Array (ILPA) were used to perform the spectral analysis. The observed Rayleigh wave phase velocity dispersion data then systematically inverted to obtain a best fitting model. The preferred model has a crustal thickness of 44+/-2 km. The upper crust consists of a ~ 8 km thick sedimentary layer (Vp ~ 5.15 km/s) above a ~ 22 km thick upper crystalline crust (Vp ~ 6.19 km/s). The lower crystalline crust is unusually slow (Vp ~ 6.75 km/s) with a thickness of ~ 14 km. The total thickness of the crystalline crust in this region of the central Zagros (~ 36 km) is similar to the thickness of the stretched margin of the Arabian Platform, suggesting that the Zagros is now in an early stage of continental collision.

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**P1.2 The Solid Earth and its Structure** - Board: 3 / **P1.2-054**

## Attenuation of seismic waves in the Charlevoix seismic zone, southeastern Canada

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We investigate seismic attenuation characteristics of the Charlevoix seismic zone that is located ~100 km downstream from Quebec City and is the most seismically active region of eastern Canada. We determine Coda Q using 583 earthquakes ($2.0 \leq M \leq 5.4$) recorded at seven stations of the Canadian National Seismic Network from 1992 to 2022. We find that the highest Q0 (Q at 1 Hz) values are at station A11 (e.g., Q0 of 109), that is the farthest station from the 1663, M~7 earthquake (D=40 km). The lowest Q0 values that we find are at station A16 (e.g., Q0 of 72) that is the second closest station to the 1663 earthquake (D=16 km) after station A61 (D=10 km). Also, we find the lowest overall average Q0 value of 72 at station A16. Based on global studies, Q0 is lower in the vicinity of large

earthquakes. Therefore, the low Q0 values at station A16 may suggest that the 1663 earthquake is located slightly southeast of the catalog epicenter, considering high uncertainty associated with historic events. An average for all the data results in a Q relationship of QC = 81f^1.06 (2 Hz ≤ f ≤ 16 Hz) for the entire region.

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**P1.2 The Solid Earth and its Structure** - Board: 4 / **P1.2-055**

## Non-volcanic tremors along west Nusa Tenggara, Indonesia triggered by large teleseismic earthquakes

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An advanced analysis was conducted on the triggered 'non-volcanic' tremors (NVT) around Tambora volcano in West Nusa Tenggara, Indonesia by 35 teleseismic earthquakes with a magnitude M>7 and epicentral distance of over 1000 km between 2020 and 2022. The waveform data were taken from the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG). The identification of triggered tremors was based on the visual detection of high-frequency bursts (1-10 Hz and 2–8 Hz) of non-impulsive and prolonged seismic energy, exhibiting coherence across multiple seismic stations and modulation by teleseismic surface waves. Among the 35 earthquakes studied, we identified four teleseismic events that triggered NVT in West Nusa Tenggara. The 2021 Mw 7.4 and Mw 8.1 Kermadec, 2021 Mw 7.3 Vanuatu and 2022 Mw 7.7 Papua New Guinea earthquakes have triggered NVT in this region. We use envelope waveform cross-correlation to locate tremors. The study revealed that amplitudes of surface waves play a crucial role in determining the triggering potential, with an observed triggering threshold of approximately 0.1 cm/s, or dynamic stress 7–8K Pa. The triggered tremors were initiated by Rayleigh surface waves. It has been observed that triggering potential is controlled by the peak ground velocity (PGV), frequency, and dynamic stress.

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## Seismicity linked to magmatism: The 2024 earthquake sequence in the fentale volcanic zone, Northern Main Ethiopian Rift

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From 27 September to 2 November 2024, a sequence of moderate earthquakes (magnitudes 4.2 to 5.3) occurred in the Fentale volcanic zone, Northern Main Ethiopian Rift. This region is characterized by active magmatism and volcanism, making it a critical area for studying tectono-volcanic interactions. The seismic events were localized near Fentale, an active stratovolcano, suggesting a potential relationship between fault activity and magmatic processes. Preliminary analysis shows that the earthquakes were concentrated within a narrow zone, likely influenced by magma migration beneath the surface. This seismic sequence may indicate fault slip triggered by magmatic intrusions, providing insights into the dynamic interplay between tectonics and volcanism in the rift system. Key parameters such as hypocentral locations, focal mechanisms, and temporal clustering were used to investigate faulting and stress orientations in the area. The findings contribute to the understanding of rift-related seismicity and volcanic hazard assessment in Ethiopia. Given the proximity of human settlements and infrastructure to the Fentale volcanic zone, these results highlight the need for continuous monitoring and enhanced risk mitigation strategies in the region.

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**Online e-Poster Session 1** - Board: 0 / **P1.2-070**

## Comprehensive Seismic Study of North Sulawesi Indonesia : b-Value, z-Value, and Earthquake Recurrence Time

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The aim of this research is to explore seismic activity in the North Sulawesi Indonesia, which lies within the Pacific Ring of Fire and is highly susceptible to significant earthquakes and tsunamis. The study involved calculating and mapping the distribution of b-values and z-values, as well as identifying the recurrence times of earthquake events. The earthquake data used were sourced from the United States Geological Survey catalog for the years 1925–2024 (100 years) and use ZMap Version 7 to analyse the data. This research found that the b-value ranged from 0.7 to 1.3, with lower values indicating the dominance of major earthquakes in subduction zones or areas of high stress accumulation. The study also found that the z-value ranged from -0.3 to -0.7, reflecting increased small earthquake activity, such as aftershock clusters or background seismicity, due to local stress release. The region has the potential for large earthquakes (M > 7.0), which are projected to occur every 50 years, while extremely large earthquakes (M > 8.0) have a recurrence time of around 150 years. Based on these findings, high risk zones can be identified by integrating these parameters, providing essential insights for seismic risk mitigation in disaster prone areas.

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**P1.2 The Solid Earth and its Structure** - Board: 6 / **P1.2-077**

# Spatial-Temporal Analysis of b-Values Along Fault Zones in the Central Himalayas Following the 2015 Gorkha Earthquake

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This study investigates the spatial-temporal distribution of b-values along five fault areas the Judi fault, Thaple fault, Kathmandu fault, Motihari-Gauri Shanker fault and the Motihari-Everest fault following the Gorkha earthquake (MW 7.8). The study area spans the central Himalayas, bounded by latitudes 26.5°–29° N and longitudes 84°–87° E. An earthquake catalogue comprising 10 500 events was compiled from the National Seismological Centre and NAMASTE Networks Nepal. The frequency-magnitude distribution reveals b-value variations across the fault areas, ranging from 0.45 to 0.69, consistent with aftershock sequences. Notably, the Judi fault, Thaple fault, and Motihari-Everest fault areas exhibit low b-values of 0.45 ± 0.02, 0.48 ± 0.02, and 0.55 ± 0.04, respectively, suggesting potential regions for future seismic activity. These low b-values align with the thrust faulting mechanisms inferred from the focal mechanisms of the mainshock and major aftershocks. Temporal analysis of b-values emphasizes fluctuations from 25 April to 12 May 2015. Among the selected regions, the Motihari-Everest fault area shows critical strain conditions, as indicated by its stepwise energy release pattern, suggesting it is mechanically locked and susceptible to future seismic events.

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# Advantages of determining an earthquake focal mechanism using Distributed Acoustic Sensing data

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Earthquake source parameters are valuable for seismology, including monitoring the Comprehensive Nuclear-Test-Ban Treaty. One needs to determine the hypocentre location, seismic moment, radiated energy, event size, and released stress drop. A stress-strain pattern of the crust is inferred from a statistical analysis of focal mechanisms. It provides information on geometry and kinematics of fault zones. Focal mechanisms of earthquakes with Mw ≥ 5 are calculated by seismological centers and published in Global CMT, USGS, and other catalogs. Focal mechanisms of weak events are commonly obtained from body wave first-motion polarities recorded by regional seismic networks. Often the networks are poor for determining focal mechanisms of weak earthquakes. In the Russian Federation, such a situation is realized in Yakutia, Transbaikalia, etc. Using pre-existing telecommunication cables as DAS sensors can fill the gap in seismological data for these regions, providing

good azimuthal coverage of earthquake sources and, therefore, significantly enlarging a number of seismic events with well-constrained nodal planes. The methods for source parameters determining, for which converting strain-rate data in ground motion quantities is not required, are especially interesting. We examine challenges of DAS using, approaches of their overcoming and discuss the potential of DAS for determining earthquakes focal mechanisms.

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**P1.2 The Solid Earth and its Structure** - Board: 7 / **P1.2-083**

## Detection of Large Displacement due to Mw 7.5 28 September 2018 Palu Earthquake using 1 Hz High Rate GNSS Data

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The devastating earthquake followed by the tsunami that occurred in Palu, Indonesia, on 28 September 2018 resulted in the death of more than 4300 people and serious damage to more than 12 000 buildings. Earthquake-induced site displacement is critical information for estimating the magnitude of earthquakes. Compared to a seismometer, which the signal clipping when recording in the near-field of large earthquakes, that may cause underestimated earthquake magnitude determination, the Global Navigation Satellite System (GNSS) records surface displacements directly, making it particularly valuable in the case of large earthquakes. We utilize high-rate 1 Hz GNSS data from the Indonesia Continuously Operating Reference Station (InaCORS) network associated with the Mw7.5 Palu earthquake and generate GNSS dynamic displacement waveforms in three components (east, north, and up) in six GNSS stations that record surface displacement. We calculated peak ground displacement at each GNSS station extracted from three-component GNSS waveform and found that the highest PGD was 292 cm at station PALP, which was located around 78 km from the epicenter. The GNSS dynamic displacement for large earthquakes will be very valuable for rapid estimation of earthquake magnitude that is needed in earthquake and tsunami warning.

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**Online e-Poster Session 1** - Board: 0 / **P1.2-093**

## A New Dynamic Simulation of the Potential Main Marmara Fault Earthquake through Incorporation of Stress Perturbation due to 1912 Ganos and 1999 İzmit Earthquakes and Interseismic Stress Load

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This research aims to create realistic earthquake scenarios for the expected Main Marmara Fault Earthquake and develop Peak Ground Velocity (PGV) maps using physics-based approaches to protect ~20 million inhabitants in the Istanbul Metropolitan and its surroundings. In this study, a new 3-D dynamic simulation scenario for the expected M≥7.0 earthquake in the Sea of Marmara, incorporates stress perturbations from the 1912 Ganos and 1999 Izmit earthquakes, along with interseismic stress accumulation from historical earthquakes, geodetic rates and heterogeneous coupling, is generated. The pre-stress distribution forms the basis to simulate dynamic ruptures, highlighting the importance of consideration of stress heterogeneities. To calculate incoming stresses from the 1912 and 1999 earthquakes, a 3-D quasi-static simulation is generated for a master scenario and simulated stresses are added to the interseismic stress load for the dynamic rupture simulation. The resulting dynamic simulation shows a ~50 cm increase in maximum slip in the Central and Eastern Marmara, corresponding to a 0.1 magnitude unit increase, with PGV contour extensions. Future work will incorporate soil amplifications and a 3-D crustal structure to enhance simulations and create intensity maps. In addition, International Monitoring System seismic data will be used due to limited observed data for future events.

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**P1.2 The Solid Earth and its Structure** - Board: 8 / **P1.2-098**

# Seismotectonics and characterization of natural and man-made events at Mpape following the 2024 Abuja earthquakes in Nigeria

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From 10 to 19 September 2024, residents of Mpape, a densely populated settlement in Abuja, Nigeria, with a high concentration of mining firms, witnessed a series of vibrations that they thought were from usual ground shakings resulting from regular quarry blasts. The duration (nine days) of the vibrations motivated this research to determine the seismotectonic nature and characterize artificial and natural events at Mpape. We adopted seismological, geological and geophysical approaches to process and analyse aeromagnetic data using the Oasis Montaj software; and seismic data covering one year retrieved from three short period local stations located within Abuja using Geotool and Seisan software, and the Matlab package. Results show the presence of a tectonic fault within Mpape, which was hitherto unknown. Analysis of the waveform data confirmed the 10-19 September 2024 vibrations resulted from many seismic foreshocks that heralded the main event located (Lat:9.217$^{o}$N, Lon:7.453$^{o}$E, Ml=3.5, depth=15km; Intensity=V); followed by a sequence of aftershocks with III-IV intensities. The seismograms also contained suspicious events with high amplitude P-onsets with no clear S waves for different days and were associated with rock blasting events; while some blasts coincided with hitherto two unnoticed seismic events of 1 and 9 November 2023 with magnitudes 2.5 and 2.7 respectively.

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**P1.2 The Solid Earth and its Structure** - Board: 9 / **P1.2-101**

## Empirical relationship among seismic and fault parameters on the Talysh dynamic earthquake zone (southern Azerbaijan)

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We combine seismic and tectonic approaches to apply the empirical relationships between fault parameters and magnitudes to assess the maximum magnitude for the prediction of intensity motion. The Talysh area in southern Azerbaijan, with 3960 km², 38054'N and 48035'E, spreads to the north through the Alborz mountains of Iran. The earthquakes are concentrated mainly in the central part of the Talysh (up to 70 km) and in the southwestern part of the Caspian Sea (up to 55 km), with the local magnitude of up to M5.5. The earthquake magnitudes calculated on the basis of the surface fault length were compared with the catalogued magnitudes. (1) a comprehensive catalogue of faults was compiled; (2) earthquake magnitude is derived from fault length, downdip rupture width; (3) the resulting fault-length-earthquake-magnitudes were compared by the math difference with catalogued earthquake magnitudes; and (4) intensity simulation of ground motion on near-fault areas was plotted. The results show the approximate consistence of the calculated fault-length-earthquake-magnitude with the catalogued seismicity. The highest intensity areas of VII are observed in the central and western parts. An intensity VI covers the majority of the Talysh zone. The results will contribute to implementing more solid analyses for advancing seismic hazard analysis.

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**P1.2 The Solid Earth and its Structure** - Board: 10 / **P1.2-104**

## Focal depth of some South Atlantic earthquakes using teleseismic P-Wave and water reverberations

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Oceanic transform faults are important tectonic structures connecting mid-ocean ridge sections, controlling their global morphology, movements, deformation, and rupture process. The complete understanding of these fracture zones relies on earthquake focal depth (Z) estimation. Z is a critical parameter for these tectonic studies that is usually difficult to estimate due to unfavorable continental seismic station distribution at teleseismic distances. Phase depths are a reliable way to estimate these depths. Still, identifying such phases may be complicated due to the low signal to noise ratio, focal depth, and rupture duration. To circumvent these difficulties, we use the methodology proposed by Huang et al. (2015) that includes the water reverberations of the depth phases in the focal depth estimation using array-stacked seismograms at teleseismic depths. In this method, a grid search procedure simultaneously estimates Z and the sea floor depth (H). We tested the methodology using both synthetics under different conditions and real earthquakes from the South Atlantic. The method performs well under several noise conditions and varying numbers of stacked seismograms from different arrays available. Finally, the radiation pattern is a key factor in estimating Z and H reliably.

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**Online e-Poster Session 1** - Board: 0 / **P1.2-127**

## Seismicity and Morphometric Studies In North Sudan

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Sudan is classified as an area of moderate seismic activity. The main objective is to study the seismic activity and estimate the morphometric aspect of the North locality. A unified Mw earthquake data for the period between 1906 to 2016 was used to construct the seismicity map. The areal distribution of the earthquake illustrated the concentration of the earthquakes in the eastern part, A Pie chart of magnitude and depth was created, the earthquakes' depth is between 2.6 and 40 km representing that earthquakes are of a shallow type. The increase of seismic activity in the study area motivated the researcher to construct the normalized water index and quantitatively assess the morphometric parameters (linear, relief and areal). The drainage patterns show eight stream orders. The logarithmic plots indicated that there is an inverse relationship between the number of streams and their Length. The earthquake data were superimposed on a normalized difference water index map and surface drainage density map to display the weak zones. The result indicates GIS techniques and DEMs data are competent for characterizing the morphometric aspect. This study will help decision makers, the governmental sector and local communities to avoid the environmental impact.

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**Online e-Poster Session 1** - Board: 0 / **P1.2-142**

## Variability of ETAS Parameters and Their Relationship with Physical Processes for Earthquake Forecasting in Africa

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Seismicity of Africa is moderate by global standards, primarily due to limited recorded earthquakes. However, moment-magnitude Mw larger than 6.0 events frequently occur along poorly understood fault lines, posing significant risks, such as the Mw 6.9 Moroccan earthquake on 8 September 2023. This underscores the urgent need to improve earthquake forecasting on the continent.

Epidemic-Type Aftershock Sequence (ETAS) models, which estimate seismic clustering in space, time, and magnitude, offer the best solution to this challenge but are hampered by catalog deficiencies, particularly in regions with sparse seismic networks. ETAS parameters may also reflect the spatial variability of crustal geophysical properties. However, tailored ETAS estimates for Africa are currently lacking.

To address this, we divided Africa into subregions and fitted ETAS models to earthquakes in each one. Parameters were compared across subregions and correlated with crustal properties. Results showed significant regional variability, particularly in parameters describing aftershock productivity ($\alpha$), temporal decay (c), and spatial distribution (d, $\gamma$), likely influenced by missing events in the catalog. Positive correlations were observed between the aftershock decay parameter p, heat flow, and the compressional-to-shear wave velocity ratio, while a negative correlation was noted with Curie depth. These findings provide a foundation for operational earthquake forecasting in Africa.

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**P1.2 The Solid Earth and its Structure** - Board: 11 / **P1.2-147**

## Significant Earthquake Scenario from the Northernmost Fault in the Aceh Region, Sumatra: Preliminary Hazard Assessment

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The northernmost region of Aceh contains an active fault capable of releasing energy with significant magnitudes. The magnification energy released along this fault can trigger significant and destructive earthquakes. This is evidenced by the seismic history of the Seulimeum Fault (the northernmost fault) in 1964 (Setiyono et al., 2019), which recorded a magnitude of M 6.5. The earthquake caused severe damage, particularly in Banda Aceh, the capital city of the Aceh Province, and in districts intersecting the Seulimeum Fault. Analyzing significant earthquake scenarios is essential to developing a better understanding of initial earthquake hazard assessment, the seismotectonic setting. The seismic scenario this study uses parameters derived from the 1964 destructive earthquake in the same fault zone. This approach is based on determining seismicity levels (Gutenberg and Richter, 1956) and general geo-structural density (Fossen, 2016). The findings suggest the potential recurrence of

significant earthquakes along the northernmost fault, with an estimated maximum magnitude of M ≥ 7. This energy release is spatially projected as a distribution of earthquake-induced ground shaking, modeled using the shear wave radiation impact from the earthquake scenario (Boore and Atkinson, 2008; Wald et al., 2005) and converted into an intensity scale for ground shaking scenarios (Worden et al., 2018).

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## Up to date Probabilistic Earthquake Hazard Assessment for North Africa

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North Africa, which includes Egypt, Libya, Tunisia, Algeria, and Morocco, stretches from the Red Sea and Gulf of Aqaba in the east to the Atlantic Ocean in the west. This current study updates the seismic hazard evaluation for North Africa by applying a probabilistic approach. It uses an earthquake catalogue from 112 BC to 2024 AD and a seismotectonic model to assess seismic activity. The analysis accounts for uncertainties in parameters such as declustering, minimum magnitude, and ground-motion prediction using a logic-tree framework. Seismic hazard is calculated for a 0.5x0.5 grid, considering rock types and spectral accelerations at different time periods (0.2s, 1.0s, and 2.0s) and peak ground acceleration (PGA). The hazard is calculated for two return periods: 475 years (10%) and 2475 years (2%) probability of exceedance of 50 years. The uniform percentile hazards spectra and deaggregation charts are plotted. The highest PGA values are found in northeastern Egypt, near the Gulf of Aqaba (up to 0.27g) and near Aswan (up to 0.18g) for a 475 year. Morocco experiences a PGA of up to 0.12g, while Algeria, Libya and Tunisia have PGA value less than 0.1g. We also use a strong motion catalog to estimate PGA across the region.

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## Two-step relocation of the seismicity of Oman

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The Oman National Bulletin produced by the Earthquake Monitoring Center, Sultan Qaboos University between 2014 and 2024 were combined with regional and teleseismic data from the International Seismological Centre bulletin. The resulting comprehensive bulletin contains 2994 events within our area of interest. We applied a two-step relocation procedure to improve the view of Oman's seismicity. We first relocated the bulletin with iLoc, a single-event location algorithm that takes into account potential correlated travel time and uses RSTT. The global 3-D RSTT crust and upper mantle velocity model was developed by Lawrence Livermore, Los Alamos and Sandia National Laboratories. Before applying the second step of our location procedures, we performed further quality control on the iLoc results by removing events recorded by less than three stations or four arrival times. We then relocated the events with Bayesloc, a non-linear Markov Chain Monte Carlo multiple event location algorithm, using the reviewed iLoc locations as input and setting tighter a priori constraints for suspected explosions. Bayesloc was run with 10 Markov chains for 80 000 iterations. The results demonstrate significant improvements in the view of seismicity and can help to identify anthropogenic events, which represent the majority of onshore events in the region.

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# Probabilistic Moment Tensor Inversion for Moderate to Strong Earthquakes in Albania and Surrounding Region Using Grond

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This study employs Grond, a probabilistic earthquake source inversion framework, to analyse moderate to strong earthquakes (Mw 3.5–6.4) in Albania and the surrounding region. Using seismic data accessed via FDSN and a locally developed velocity model, moment tensor inversion is conducted to characterize complex regional seismicity. While the analysis primarily focuses on natural seismic events, the study emphasizes moment tensor inversion's utility in distinguishing between natural and human-made events when necessary. The modelling incorporates deviatoric and double-couple source types, utilizing radial, transverse, and vertical waveform components in the frequency range of 0.01–0.07 Hz. Forward modelling is based on pre-calculated Green's Functions (GFs) from Pyrocko GF Stores, created with the Fomosto tool and optimized for layered media using the QSEIS method. This approach enhances computational efficiency without compromising accuracy. To mitigate bias and quantify uncertainties, Grond integrates advanced bootstrapping techniques, including Bayesian and residual bootstrapping, ensuring robust source parameter estimation even with noise or modelling limitations. This research contributes to understanding tectonic processes in the region, showcasing Grond's effectiveness in seismic studies and its implications for seismic hazard assessment and identifying atypical seismic events.
Keywords: MTI, Grond, Bayesian, Green's Functions, Albania, Pyrocko

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## Seismicity of the Shkodër-Pejë Fault Zone: 50 Years Overview

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The Shkodër-Pejë zone is an internal transverse fault zone with active normal faults stretching east-west, primarily along the boundary of the Mirdita ophiolitic zone. This fault divides the geological structure of the Albanides into two parts: the northern part, which continues with the Dinarides, and the southern part, which continues with the Hellenides. The region has been historically affected by strong earthquakes, including those on 1 February 1662 (Ms6.0, Pejë, Kosovo),3 July 1855 (Ms6.3 Shkodër), 1 June 1905 (Ms6.6 Shkodër) and 27 August 1948 (Ms5.5). Major earthquakes have been generated along the edges of this fault in previous centuries. This seismogenic zone presents a significant seismic hazard for northern and north-eastern Albania, southern Kosovo and southern Montenegro. Based on analysis of event parameters and seismicity features from 1971 to 2024, a total of 1187 earthquakes have been recorded, including a magnitude 4.5 event on 27 October 1986. Recent seismic activity in the Shkodër-Pejë zone is characterized by low energy events, mostly generated in the upper and middle crust, with fewer events in the lower crust. This study aims to define seismic typology, earthquake source parameters, and shed light on the seismotectonics of the region, highlighting the seismic risk.

Keywords: Earthquake, Seismicity, Fault Zone, Focal Mechanism.

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**P1.2 The Solid Earth and its Structure** - Board: 15 / **P1.2-288**

## Improving a 3-D global propagation model via SMART cables and other sea floor data

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Global seismic models suffer from heterogenous source and receiver distributions. The greatest gaps are beneath the oceans, ~70% of the Earth's surface. Most teleseismically observed earthquakes occur at plate margins, while most seismic sensors are on land. Ocean Bottom Seismometers (OBSs) offer some improvement in sensor distribution, but OBS deployments are limited in extent and duration. In a year-long deployment there may be ~100 earthquakes of magnitude >6, but many are nearly co-located, reducing added ray coverage. Nearshore cabled arrays of OBS have longer lifetimes but do not offer novel sampling for teleseismic arrivals. We thus analyse teleseismic records from over

4000 P phase arrivals for 240 events using abyssal OBS data from Ocean Bottom Seismic Instrumentation Pool (OBSIP) experiments, and add these to our database. These provide novel paths for tomography, but only modest improvement in resolution and travel-time uncertainty. Future seismic data from Science Monitoring And Reliable Telecommunication (SMART) Cable sensors will revolutionize seismology in terms of more complete global models, better distribution of sensing, and significantly improved resolution and travel time uncertainty estimates. We compare global models with and without OBS, and we examine model resolution and travel time uncertainty improvements with the SMART sensors.

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# Data Availability and Prospects of Probabilistic Seismic Hazard Studies in the Sub-Saharan Africa Using Integrated Techniques

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Probabilistic Seismic Hazard Assessments (PSHA) have not been conducted in large parts of Sub-Saharan Africa (SSA), due to incomplete earthquake catalogues, sparse seismic networks, etc; raising concerns on needed information for planning and disaster risk management. This study aims to bridge this research gap using modern techniques. Updated catalogue from Local Networks, significant data from the Comprehensive Nuclear-Test-Ban Treaty Organization's National Data Centers, International Seismological Centre, and publications, spanning 1615-2024 with threshold and maximum moment magnitudes (Mw) of 4.0 and 6.8 formed the data set. The catalogue declustered and harmonized to Mw was used with available geological data to delineate area source zones and compute earthquake hazard parameters. Four ground motion prediction equations (GMPEs) for tectonically similar regions to SSA were implemented using logic tree formalism in the calculation, with all equations weighted equally. Within the 1-1000-year period considered, the computed Gutenberg-Richter b-value, activity rates, and regional maximum possible magnitudes ranged from 0.69-1.0, 1.6-2.1, and 5.2-7.2, respectively. Peak Ground Accelerations ranged 0.02g-0.2g for a 10% chance of exceedance in 50 years, and seismic hazard maps for 0.1s, 0.2.s, 0.3s, 0.5s, and 0.15s periods were produced. The results are expected to significantly contribute to planning in the vast region.

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**P1.2 The Solid Earth and its Structure** - Board: 17 / **P1.2-356**

# Seismicity, tectonics and radon emission measurements in central Ionian Islands (Greece)

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In the Ionian Islands, historical records dating back to 1400 A.D. reveal a recurring pattern of large earthquakes (Mw>7.0) involving multiple fault rupturing, complex rupture dynamics, and/or the triggering of additional earthquakes. Efforts to mitigate future casualties and economic losses require detailed investigations into past destructive earthquakes and seismic hazard assessments at finer resolutions. Over the past two decades, significant advancements in the region's seismic network have led to highly accurate earthquake relocations and a refined understanding of fault networks. It has become evident that recent main shocks are associated with specific fault segments, which subsequently transfer stress to neighboring faults. Active faulting, manifested by high seismic activity, combined with fluid flow, plays a critical role in the transport and dispersion of radionuclides. Radon ($^{222}$Rn), a radioactive noble gas with a half-life of 3.8 days, emanates from the upper lithosphere because of the alpha decay of radium ($^{226}$Ra) in the uranium-238 decay series. Once dissolved in water, radon distribution becomes particularly relevant for scientific investigations. The installation of novel sensor systems in the study area is expected to provide new insights into the correlation between imminent earthquakes and variations in radon emissions.

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**P1.2 The Solid Earth and its Structure** - Board: 18 / **P1.2-359**

# Tectonic settings and neo-tectonics of the Aegean Sea as seen from space

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The Aegean Sea is one of the key regions for the understanding of fundamental tectonic processes, including continental rifting. In addition, the continuous seismicity is attributed to its tectonic settings, which indicates the activities of these tectonics. Thus, tectonics and geodynamics of this region have always been the attention of many interested in earth sciences. Radar altimetry data has been used to derive gravity and its variations over the world's oceans, and an excellent tool for mapping sea floor structures, including tectonics, sea mounts and rifts. On the other hand, the Gravity Recovery and Climate Experiment (GRACE) satellite mission has widely demonstrated its sensitivity to ongoing mass redistribution within the various sub-systems of the Earth. Finally, Gravity field and steady-state Ocean Circulation Explorer (GOCE) satellite is the first satellite mission that observes gradient of the Earth's gravity field from space. Integrated satellite gravity data have been used to delineate the tectonic settings and the neo-tectonics of the Aegean Sea.
Results show important zones of mass discontinuity in this region correlated with the seismological activities and temporal gravity variation. This study indicates the importance of considering spatial and temporal gravity to the deformation and tectonic studies for completeness of the geodynamic studies

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## Incoherent Seismic Array Processing Using Kurtosis: A Case Study from the Grane Oilfield

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Seismic arrays are known for their superior detection capabilities compared to single sensors. Array processing techniques, such as FK analysis, can estimate slowness and back azimuth, improving earthquake location estimates. However, these techniques require signal coherence across the array. Factors such as geological conditions and sensor spacing can lead to signal incoherence. Several studies suggest that characteristic functions, such as STA/LTA or envelopes, can enhance signal coherence, making it possible to perform FK analysis. In this study, we test an alternative characteristic function for incoherent array processing: the kurtosis function. This methodology was developed using a seismic network deployed on the seabed at the Grane Oilfield, offshore Norway. The dataset consists of 10 sensors with significant spacing, which contributes to signal incoherence. Despite this challenge, the recursive kurtosis function enabled the estimation of slowness and back azimuth for 8 out of 10 tested events. Integrating these array parameters into earthquake location estimates revealed notable shifts in event positions. The method developed in this study has potential applications for IMS arrays, where signal coherence presents a significant challenge. For instance, it could be applied to arrays such as MJAR in Japan, which faces incoherent signals due to complex subsurface geology.

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**P1.2 The Solid Earth and its Structure** - Board: 20 / **P1.2-373**

## Moho Depth and Average Lithospheric Structure Beneath the Beni Suef-Siwa Sector, Egypt

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This study focuses on understanding the crustal and upper mantle structure beneath northern Egypt using seismic data from 500 records collected by the Egyptian National Seismological Network (ENSN). Two broadband stations in the region were used to investigate crustal properties through

joint inversion of surface wave dispersion curves (Rayleigh wave phase velocity) and receiver functions (RFs). Receiver function analysis, with the H-K stacking method, helped determine the Moho depth, crustal thickness, and the Vp/Vs ratio. The study yielded 1-D shear velocity models for the two areas of interest: Beni Suef (NBNS) and Siwa (SWA). The results complement the observations of RFs after performing H-K stack to obtain Moho depth across the area. Measurements from dispersion curves and RFs are used in Pesianoss joint inversion to retrieve a series of 1-D shear wave velocity models. The integration of both methods allows for complementary insights into the crustal thickness, composition, and velocity distribution. The crust beneath Beni Suef is characterized by three layers, with a thickness of 29.2 ± 1.3 km and a Vp/Vs ratio of 2.2 ± 0.07. In Siwa, the crust has three horizontal layers, with a thickness of 33.5 ± 2.2 km and a Vp/Vs ratio of 2.0 ± 0.09.

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**P1.2 The Solid Earth and its Structure** - Board: 21 / **P1.2-377**

## The stress mapping in the Bolivian Orocline through probabilistic moment tensor approach

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The Central Andes is a geologically complex region due to various tectonic processes, including extensional and compressional strains. This complexity is particularly evident in areas like the Bolivian Orocline, where a lack of geophysical equipment, such as seismic stations, often hinders studies related to tectonics and seismology. Despite this limitation, new methodologies have been developed for the available data. One such approach is an open source method for performing moment tensor inversion based on probabilistic and Bayesian optimization. By merging data from the International Monitoring System, open seismic network data, and local information, we obtained 13 new moment tensors. These tensors map the stress in the Central Andes, showing extensional forces in the Altiplano and compressional forces in the Sub Andes. Our results suggest a dynamic equilibrium within this context, indicating that some tectonic systems are partially blocked, which motivates us to continue this research.

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**P1.2 The Solid Earth and its Structure** - Board: 22 / **P1.2-384**

## Application of anisotropy of magnetic susceptibility fabrics and magnetic data analysis to determine the Stress analysis and tectonic trends of Southern Eastern Desert, Egypt.

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In our present research, we have analysed and interpreted the aeromagnetic data and anisotropy of magnetic susceptibility (AMS) fabrics to highlight the structure and tectonic settings of the study area. We used horizontal gradient and tilt derivative to identify deep sources and faults. We applied the Euler Deconvolution technique to provide reliable information. The results indicated significant variations in the magnetic properties across different regions, suggesting complex geological formations. Furthermore, the findings contributed to a better understanding of the tectonic evolution of Egypt, highlighting areas of potential mineral deposits and seismic activity. 93 rock samples were collected from 10 sites. The study found that the main stress and tectonic trend is NE-SW in the south-eastern desert of Egypt. The results align with previous stress directions from geological, seismological, and tectonic analysis. This alignment indicates a consistent geodynamic regime that has shaped the region over millions of years. Additionally, understanding the tectonic behaviour of the south-eastern desert may also provide valuable information for assessing potential risks associated with future seismic activities. This knowledge is crucial for enhancing preparedness and mitigating the effects of potential earthquakes in this geologically active region.

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## Uncertainty Analysis of Moment Tensor Solutions for Local Earthquakes around Colombia using ISOLA2024

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The quality of seismic moment tensor catalogs is crucial for studying seismicity, active faults, seismic hazards and seismic risk assessment. The National Seismological Network of Colombia routinely and semi-automatically calculates centroid moment tensor (CMT) earthquake solutions with Mw > 4.2 using different full displacement waveform inversion methods. Recently, the Gisola software was installed to execute ISOLA automatically, especially for small and moderate earthquakes. For earthquakes with Mw > 5.0, the reliability of the CMT is evaluated by comparing it with the Global-CMT solutions. However, reliable solutions for small to moderate earthquakes are limited due to uncertainties arising from data and theoretical errors. Small and moderate earthquakes typically have significant uncertainties in their moment tensors and are likely artifacts of inversion or result from complex tectonic settings. We analyse the uncertainty of CMT solutions using the latest tools in the ISOLA2024 software, which incorporates existing covariance methods. ISOLA2024 incorporates basic statistics of non-DC components and their variations across grid-searched source positions, thereby enabling an evaluation of the robustness of the solutions.

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# Unusual earthquakes of the Central Kalahari Game Reserve Botswana: Anomalies in a Stable Continental Plate

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Botswana is generally regarded as a seismically quiet region, characterized by low to moderate seismic activity. This relative stability is attributable to its location on the stable continental part of the African Plate, far from tectonic plate boundaries (Roger M Key and Neil Ayres, 1998). Nevertheless, on 3 April 3 2017, at 19:40:16.95 local time, an unexpected earthquake with a magnitude of 6.5 Mw struck the Central Kalahari Game Reserve (CKGR). Fortunately, the event's impact was mitigated by the region's remote location, sparse population, and limited infrastructure, resulting in minimal damage. Prior to the establishment of the Botswana Seismic Network (BSN), the seismicity of Botswana was not well documented due to the absence of systematic recording. The historical record of major seismic events in Botswana began with two significant earthquakes in the Okavango Delta Region in 1952. The first event, on 11 September 1952, had a Richter magnitude of 6.1. This was followed by a 6.7 earthquake on 11 October 1952 (Reeves, 1972). Despite the lack of comprehensive data at the time, these events provided important insights into the seismic potential of the region. The deployment of the BSN has since improved the documentation and understanding of seismic activities in Botswana.

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**P1.2 The Solid Earth and its Structure** - Board: 26 / **P1.2-413**

# From Normal to Strike-Slip: Stress Regime Transition in Egypt and its Implications

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Undoubtedly, the study of stress tensor inversion and the identification of the types of affected forces in any region are of paramount importance in the fields of seismology and earthquake hazard analysis. In this study, we comprehensively collected all available focal mechanism solutions for earthquakes in the vicinity of Egypt. Utilizing the Kagan angle to assess the homogeneity of the focal mechanism solutions, we obtained homogeneous and reliable solutions, thus enabling us to calculate the stress tensor inversion. Consequently, a comprehensive study was conducted on the stress tensor inversion, focusing on both northern and southern Egypt. A comparison was made between the stress tensor derived for these regions, revealing a transition from normal stress in the northern region to a strike-slip regime in the southern one. This observation prompts further investigation into the causes of this transition and its potential correlation with regional tectonic activity.

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**P1.2 The Solid Earth and its Structure** - Board: 27 / **P1.2-465**

## Effect of Earthquakes Epicentral Distances on Peak Ground Acceleration Values Recorded By the Egyptian Strong Motion Network (ESMN)

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It is well known that structures can be damaged by earthquake shaking caused by the rapid rupture of the fault, which releases the stored energy that can result in significant loss of life and property. For economical and hazard aspects, the general seismological laboratory, seismology department, NRIAG, made the first step of hazard mitigation and vulnerability of buildings and structures by constructing the Egyptian Strong Motion Network (ESMN), trying to get a better understanding of structure vulnerability in urban areas in Egypt. The primary goal of this study is to define hazard zones within the urban areas to assess structural vulnerability. Analysis was carried out using 2023 earthquake data. In 2023, Egypt was struck by about one hundred thirty earthquakes in the magnitude range (3.5–7.9) with different epicentral distances (30–900 km). Using peak ground acceleration in terms of magnitude, source to site distance, tectonic environment, and source type has been a key research area in seismic hazard estimation studies for attenuation of earthquakes (Sharma 2000). The primary results showed that the values of PGA are not just affected and decreased by epicentral distances but are mainly dependent on site effects and local amplification.

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## A Compilation of Ground Truth Events in Australia

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We have compiled ground truth seismic events for the period of 2007-2024 that occurred within Australia. These events originated from either natural seismicity or mining-induced seismicity and mining blasts. Each event has been assessed on individual criteria, including the surface rupture, satellite imagery, temporary seismic installations or aftershock kits. GT events range from GT-1 to GT-10. Given the sparsity of existing seismic networks, either IMS or non-IMS, in the Australian continent and the low level of seismicity, it is critical to have ground truth seismic events to calibrate velocity models across the continent. The magnitude of events ranges from Mw 3.7 to 6 and have been well recorded across multiple networks, including IMS, AU, Australian School Station network

S1, II and IU and local, or temporary seismic networks. We have provided the source parameters and seismic arrival times for P and S waves. The source parameters and arrivals will help constrain 3-D tomography models.

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**Online e-Poster Session 1** - Board: 0 / **P1.2-497**

## Detect ground vibrations caused by earthquakes or explosions

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In 2024, Cambodia experienced several seismic events, primarily originating from neighboring regions, notably Viet Nam. These earthquakes were felt in various parts of Cambodia, including Ratanakiri province. Notable Earthquakes Near Cambodia in 2024: 28 July 2024: A magnitude 5.1 earthquake occurred near Ratanakiri province. The tremors were felt in the area, marking a significant seismic event for the region. 25 August 2024: A magnitude 3.6 earthquake was recorded 213 km north-northeast of Lumphat, a town in Ratanakiri province.
EARTHQUAKE LIST: 20 August 2024: A magnitude 4.2 earthquake occurred 206 km northeast of Lumphat.
EARTHQUAKE LIST: 3 December 2024: A magnitude 3.9 earthquake was detected 223 km northeast of Lumphat. These events highlight the seismic activity in regions adjacent to Cambodia, with tremors occasionally affecting Cambodian provinces, especially those close to the border. While these earthquakes were perceptible, there were no immediate reports of significant damage or casualties within Cambodia.

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**P1.2 The Solid Earth and its Structure** - Board: 29 / **P1.2-512**

## Vulnerability and Earthquake Risk Assessment for Buildings in Kuwait Governorates, Kuwait

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Studying the seismic risk of buildings and infrastructure in Kuwait is crucial for sustainability and urban development. The probabilistic seismic risk was computed to evaluate the economic and human loss in the Kuwait governorates of Al Farwaniyah, Mubarak Al-Kabeer, Sabah Al Ahmad, Hawally and Al Jahra to help emergency planners design plans to control or mitigate future risks. This study required incorporating the seismic hazards to Kuwait from seismic sources, the exposure risks, and vulnerability, including the properties of buildings and infrastructure in each governorate. The economic loss for each exposure element was calculated using probabilistic metrics. These metrics are the Loss Exceedance Curve (LEC), the predicted Average Annual Loss (AAL) and the Probable Maximum Loss (PML). Seismic risk maps were also created to provide all the necessary information for housing institutions, governments, and transportation, as well as decision makers to reduce infrastructure vulnerability and to design or improve appropriate building codes. Thus, investors, governorates, and insurance institutions can develop effective plans to be used in the reconstruction, renovation, and emergency response to protect vulnerable areas from deteriorating social and economic conditions.

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## Assessment of local Seismic records and the largest earthquake magnitude in Comoro-Islands between 2017 and 2021

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The Comoros Volcano Observatory has recorded significant seismic activity through the local seismic network in recent years. The evolution of the local seismicity, often assessed as volcano-induced seismicity, raises numerous inquiries on the seismo-volcanic hazards and the Magnitude records in the Comoro Archipelago. Data from the Karthala Volcano Observatory (KVO) bulletin between 2017 and 2021 revealed a Magnitude Md ~ 0 to 4.95 ~. An inclusive catalog of the collected data available in this period frame is made, and spatial distribution of every year is created. A high record of seismicity is noticed for 2018 with the largest calculated magnitude. Based on previously published studies, the reservoir of magma that caused the huge earthquake swarm with the highest record of seismic activity generated a Mw 5.9 on 15 May during the sequence of May 2018 in the east of Mayotte Island, an important local and regional volcano seismicity acknowledged in addition to the Karthala volcano seismic behavior in Grand Comore Island. This study describes the seismic distribution in the time frame of five years successively, the evaluation from each year, and the impact based on the volcanic influence in the Comoro Archipelago as part of the East African Rift System.

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**Online e-Poster Session 1** - Board: 0 / **P1.2-537**

## The geodynamics of Sulawesi Island and its structures based on P

## wave delay time, ray-tracing, and shear wave splitting phenomena

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The various microplates collided and resulted in Sulawesi Island. Compression stress became the main force at the beginning of tectonic episodes. Nowadays, two subductions still exist. However, it is still an open question whether those two subductions significantly contribute to seismic wave arrival times. The global 1-D and 3-D velocity models are used to identify the residual patterns in Sulawesi Island and its surroundings. The low frequency band (0.05-0.2 Hz) represents regional features, while the high frequency band (0.5-1.5 Hz) is more sensitive to local features used in this study. A broad frequency band (0.01-1 Hz) is also used to accommodate the low and high frequency parts. Residual arrival times are also frequency and azimuth dependent, varying with the medium through which the ray path travels. Besides, we use deep local seismic to represent the past and present internal deformation. In addition, we use teleseismic data to identify the shear wave splitting phenomenon from plate motion. The delay time is also considered to determine the arrival time of the S and S(K)KS phases. The delay time and shear wave splitting phenomenon contributed more to the northern part by the subduction system. Then, the basin and faults contributed more to the central and southern parts of Sulawesi Island.

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## Investigating the Subsurface Geometry of the Mogod Fault System in Mongolia Through Earthquake Hypocenter Relocation

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The 5 January 5 1967 Mogod earthquake (Ms 7.5, Mw 7.1) in Mongolia caused significant surface faulting and has long been a focus of seismological studies. Recent collaborative research (2022–2024) between the Institute of Astronomy and Geophysics, Mongolia, and the Korea Institute of Geoscience and Mineral Resources (KIGAM) has advanced the understanding of this fault system. This study focuses on refining the geometry of the Mogod fault system in the Bulgan Province by reassessing earthquake hypocenters and exploring subsurface fault interactions.

A key area of investigation is the junction at 48.2°N, 103.05°E, where north-south (N-S) and north-northwest–south-southeast (NNW–SSE) fault systems intersect. Despite the lack of surface evidence linking these faults, subsurface structural interactions have been inferred by relocating seismic events using the SeisComP module. This approach has revealed four critical zones that merit further study, providing insights into fault behavior and seismic hazard potential.

This research holds significance for both regional and global seismic monitoring, particularly in advancing methodologies for analysing earthquake sources and improving fault system models. These contributions directly support the Comprehensive Nuclear-Test-Ban Treaty's mission of enhancing seismic event discrimination and understanding tectonic processes.

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**P1.2 The Solid Earth and its Structure** - Board: 32 / **P1.2-592**

## Development of a Fault database and 1-D seismic velocity Model for Madagascar: Implication for Tectonic Studies

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This study presents the development of a comprehensive fault database for Madagascar, created by integrating information from available geological surveys and published articles. We have compiled a detailed catalog of faults throughout Madagascar, incorporating data on fault geometry to determine size, length, and dip angle of the fault, and tectonic setting to identify the relative motions' effect on faulting. The database encompasses 536 identified faults, which are classified according to published studies and activity status, as reported by the respective authors. Our objective was to categorize faults as active, non-active or non-identified. We have also correlated the fault zones with historical earthquake events. Preliminary analysis indicates a significant spatial association between active fault lines and historical earthquake data. Furthermore, one-dimensional velocity models are integrated into the database to provide insights into subsurface structure and seismic wave propagation. This database will benefit a wide range of audiences and serve as a valuable resource for future tectonic studies and hazard assessment for Madagascar. The data set will support ongoing research by offering an accessible platform for querying fault data and its correlation with seismic activity using seismic data from the National Data Center.

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## Application of the Coda Calibration Tool Methodology to Intermediate Depth Events in the Vrancea Region, Romania

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The Vrancea region is renowned for its intense seismicity, encompassing both crustal and intermediate-depth earthquakes derived from distinct sources. Crustal seismicity is primarily associated with the deformation of the overlying crust, while subcrustal earthquakes arise from a vertically extended

source zone between 60 and 180 km within a sinking lithospheric slab. This unique region generates two to four events per century with M>7 within a confined volume, making it an ideal natural laboratory for testing the Coda Calibration Tool (CCT). The CCT, a Java-based application, has been recently enhanced to include hypocentral distance to calibrate one-dimensional narrowband coda models. The tool relies on empirical relationships between stable coda wave properties to estimate average source parameters, such as moment magnitude (Mw), radiated energy, apparent stress, and corner frequency. These parameters are generally more accurate than those obtained from traditional direct-wave methods, particularly in regions with complex seismic wave propagation. The seismic characteristics of Vrancea provide valuable constraints for calibrating path terms in the CCT, particularly across varying depth intervals of the intermediate-depth source zone. With events ranging from Mw 3.5 to 6.0 and minimal aftershock contamination, Vrancea offers an ideal setting for refining the CCT's calibration process.

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**P1.2 The Solid Earth and its Structure** - Board: 34 / **P1.2-615**

## Crustal and Upper Mantle Structure of the Kenyan Rift: Insights from Receiver Function Analysis

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The East African Rift System (EARS) is a prominent continental rift zone, extending over 3000 km from the Afar Triple Junction to Mozambique. Its Kenyan segment features fault-bounded basins, volcanic activity and seismicity, making it an ideal site for investigating crustal structure and rifting mechanisms. Previous geophysical studies revealed significant variations in crustal thickness along the rift axis, with thinning toward the north and thicker crust beneath the Tanzanian Craton and Mozambique Belt. However, detailed investigations with broader spatial coverage remain limited. This study utilizes data from 20 broadband seismic stations, including temporary deployments like GRAILS and permanent stations such as KMBO. Receiver function (RF) inversions and apparent S wave velocity analyses reveal localized crustal thinning within the rift zone. A high velocity lower crust (HVLC) beneath the rift is interpreted as modified mantle lithology, suggesting crustal thinning accompanied by anomalous upper mantle material. A regional Moho depth model integrating these findings with prior studies confirms localized thinning along the rift. These results enhance understanding of crustal dynamics in the Kenyan Rift and provide insights into mechanisms driving continental rifting processes.

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**Online e-Poster Session 1** - Board: 0 / **P1.2-639**

## Spatial-Temporal Distribution of b-Value in Albania and its Surroundings Over the Last Decade

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Albania, situated on the Adriatic microplate boundary, experiences high seismicity. The Gutenberg-Richter relationship, characterized by the a and b values, is crucial for understanding seismicity and forms the foundation for seismic hazard assessment. Using ZMAP7, we analysed seismicity in Albania (18.5–21.5° longitude, 38.0–43.0° latitude) from 2015 to 2024. The declustered seismic catalog, processed with the Gardner-Knopoff method, allowed for the calculation and spatial visualization of a and b values. Regions with significant b-value variations, indicating seismicity changes, were identified. Temporal analysis further revealed b-value fluctuations before and after significant earthquakes (M > 5.5). Consistent with global observations, low b-values were detected prior to large earthquakes, highlighting their potential as a forecasting indicator for major seismic events.

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## Seismic Event Discriminations in the Kumtor Deposit Area (Kyrgyzstan)

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The Kumtor gold mine is located on the northwestern slope of the Ak-Shyirak ridge of the Central Tien Shan, at an altitude of 5200 m. Since 1997, the Kumtor has been carrying out commercial open-pit gold mining; several hundred open-pit blasts are carried out on its territory every year. In addition to blasts, tectonic earthquakes and landslides are recorded on the territory of the deposit. Monitoring of seismic events in the Kumtor mine area is carried out by seismic stations of the regional networks of Kyrgyzstan, a local seismic network installed in the deposit area in 2022, as well as stations from other Central Asian countries, including those in the IMS network.

The seismic regime of the deposit area was studied, the possible influence of both anthropogenic factors and strong earthquakes of Central Asia on it was investigated. The features of the wave pattern of quarry explosions and earthquakes were studied. The parameters of seismic events were refined using the double difference method. Records of the strong motion accelerometer located on the territory of the deposit were analyzed.

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# Advancing Focal Depth Estimation Techniques: A Case Study from Mongolia

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Focal depth is a critical parameter in earthquake monitoring, offering insights into seismic processes and tectonic behavior. This study employs the Depth Scanning Algorithm (DSA) to determine the focal depths of 3388 seismic events recorded between 19 December 2022 and 26 August 2024, in the Mogod fault area, Mongolia. As part of an international collaboration with KIGAM, 10 temporary seismic stations were strategically deployed to enhance spatial coverage and improve event localization accuracy. The DSA method identified depth phases (e.g., Pg, sPg) within waveform data, with focal depths ranging from 2 km to 29.7 km. Results revealed a predominance of shallow events (<10 km), reflecting active tectonic processes, alongside deeper events indicative of complex geological settings. Sub-cross sections along the Mogod fault system highlighted distinct fault geometries and behaviours, underscoring the heterogeneous nature of the region's seismicity. This research demonstrates the effectiveness of DSA in focal depth determination, providing a deeper understanding of the Mogod fault's seismic behavior and contributing to improved seismic hazard assessment. This study also highlights the critical role of regional and international collaborations in advancing seismological research. *Keywords: Focal depth, Depth Scanning Algorithm, seismicity, Mogod fault, tectonics, seismic hazard assessment*

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**P1.2 The Solid Earth and its Structure** - Board: 37 / **P1.2-714**

# Background seismicity for parts of the northern Korean peninsula

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Tens of papers have reported small seismic events at shallow depth in and near the northern regions of the Democratic People's Republic of Korea. They often characterize the events as aftershocks of specific nuclear test explosions (NTEs). Here, we report an analysis of about six years (2004 to 2010) of seismic data recorded by the Dongbei Seismographic Network (DBSN) that in addition to such NTE aftershocks finds low-magnitude seismic events occurring in significant numbers (several hundred per year), in or near these northern regions. The events appear also to entail natural background seismicity, and blasting activity. The DBSN was installed and operated under the leadership of Kin-Yip Chun (see his papers in the October 2009 issue of the Bulletin of the Seismological Society of America, also doi: 10.1785/0120160111 for some details of the network and its uses). The DBSN data archive has been openly available in recent years (currently at Earthscope). We describe simple discriminants that help distinguish between natural and anthropogenic seismic events for this dataset. Our research demonstrates a capability to study small seismic events (below magnitude 3) in regions of significant activity using methods of detection, location, and discrimination based on the use of whole waveforms.

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## Shear-wave attenuation in northeastern and eastern Iran and its application in source parameters estimation of the local and regional earthquakes

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We analyzed 2,853 seismograms from 294 earthquakes in northeastern Iran, with ML ranging from 1.5 to 5.5. Our findings indicate that at distances less than 71 km, corresponding to the attenuation of the direct seismic waves, horizontal components decay more rapidly (R-1.16) than the theoretical decay rate of 1/R. Between 71 and 151 km, where direct waves are joined by postcritical reflections off intracrustal and Moho discontinuities, spectral amplitudes remain relatively constant; however, beyond 150 km, associated with the Lg phase, amplitudes decay at a rate of R-0.5. The regional seismic inelastic attenuation model is expressed as 121f^0.60 for frequencies between 0.5 and 15 Hz. By determining the region-specific attenuation model and site-specific amplification functions, we systematically calculated moment magnitude, MW, and stress drop values for earthquakes in the region based on isolated earthquake source spectra. We observed heterogeneity in event-specific stress drops, spanning three orders of magnitude from 0.1 to over 100 MPa, with an average value of 5.1 MPa. Notably, stress drop values in the intraplate region south of latitude 36° N were more than twice as high as those in the northern interplate zone, underscoring the importance of considering this disparity in earthquake hazard and risk assessments.

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**Online e-Poster Session 1** - Board: 0 / **P1.2-751**

## Improved event location: Relocation of the 22nd June 2024 M 4.4 earthquake in Kenya using Local and Regional Networks

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Accurate seismic event location is essential not only for the Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification but also for national data centers in order to advice national governments. Following the 22nd June 2024 M. 4.4 earthquake locating in Kenya we improve the location of CTBTO at 2.228° S and 39.18444° E with Mb 4.1. The event is also reported by the USGS to be located at

2.2896° S, 39.1603° E. A total of 28 stations including 20 temporary local stations improved the location significantly using geotool and seisan software. The new focal location is 2.121° S and 37.857° E with a reverse fault focal mechanisms where the strike is 236°, dip 50° and rake 83° and a coda magnitude of 3.2. The new location falls close to known fault line and known seismic source area. This work demonstrates the critical role of combining local and regional data in improving event accuracy and verification capabilities, aligning with SnT2025's goals of fostering innovation, strengthening cooperation, and building resilient scientific networks for global security.

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**P1.2 The Solid Earth and its Structure** - Board: 39 / **P1.2-760**

## A new Seismicity map for Kenya (1895 to 2020) and its implications for hazard

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A new seismicity map for Kenya is compiled from nineteen catalogs with 7,726 events spanning 1895 to 2020. The magnitude ranges from Mw 2.5 to 7.0 and a b-value of 0.60, for three magnitudes of completeness (Mc) 3.1, 4.0, and 4.8. The seismicity reveals a complex and dense seismic activity across Kenya, where the South Kenya Rift and the Nyanza Rift have the highest seismicity trending north-south and northeast-southwest. Away from the rift, the seismic is diffuse. The Kenya dome serves as an axial divide. The volcanic zones exhibit significant seismicity close to and near the tertiary volcanic, e.g. Chyulu Hills and Mt. Kilimanjaro, with seismic trends aligning northwest-southeast and northeast-southwest. The map suggests the presence of a magmatic body patched around the Kenya Dome, the Kenya Rift, and associated volcanic centers. The low b-value indicates an incomplete dataset, common in active tectonic regions. This new seismicity map represents the most comprehensive coverage and provides valuable input for seismic hazard assessments. The Seismicity suggests moderate activity, which correlates to moderate hazard levels. Keywords: seismicity, seismicity distribution patterns, implication to hazard.

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**P1.2 The Solid Earth and its Structure** - Board: 41 / **P1.2-825**

## Seismicity in Southern Brazil: Analyzing the Nature of Events

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The southern region of Brazil, comprising the states of Rio Grande do Sul (RS), Paraná (PR), and Santa Catarina (SC), exhibits low seismic activity compared to other regions of the country. However, it has experienced significant events over time. Notable earthquakes include a magnitude 5.9 event in 1939 on the continental margin, a magnitude 5.5 event in 1948 near the Uruguay border, and a magnitude 5.2 event in 1990. In total, over 30 events with magnitudes exceeding 3.5 have been recorded across the region. The region is predominantly within the Paraná Basin, characterized by Mesozoic sedimentary rocks and Precambrian crystalline basement. Additionally, the region has experienced five cases of seismicity induced by reservoirs (SIR): Machadinho, Itá, and Barra Grande, all in SC; and Capivari and Capivara, in PR. The largest reservoir in the area, Itaipu, has not reported any cases of reservoir-induced seismicity (RIS). This study aims to provide a comprehensive analysis of the seismicity in southern Brazil, investigating its nature, causes, and the influence of geological and anthropogenic factors using data from the Brazilian seismic catalog SISBRA.

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**P1.2 The Solid Earth and its Structure** - Board: 42 / **P1.2-829**

## Data Quality Assessment of CTBT Auxiliary Station Jayapura (AS41 JAY) Using Cross-Correlation Techniques

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The Comprehensive Nuclear-Test-Ban Treaty (CTBT) Auxiliary Station AS41 in Jayapura plays a critical role in regional seismic monitoring as a broadband station. This study evaluates the data quality of AS41 using cross-correlation techniques to assess its performance relative to neighboring short period stations. The analysis highlights that AS41 records a significantly higher number of seismic events compared to nearby short period stations, attributed to its broadband design and superior sensitivity. The findings underscore the importance of AS41 in enhancing regional seismic event detection and provide insights for optimizing the integration of broadband stations into global seismic networks.

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**P1.2 The Solid Earth and its Structure** - Board: 43 / **P1.2-858**

## The Detection of the Earthquake Swarm of the 2013 Solomon Islands M8.0 Earthquake at Santa Cruz Islands

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An earthquake swarm is a series of seismic events that occur in a local area over a short period of time. For a cluster of moderate earthquake activities of the earthquake swarm to have occurred within few days before the main shock is unusual in the Solomon Islands seismic activities from past historical seismic data records. However, before the M8.0 earthquake that triggered a tsunami on the 6th of February in 2013, clusters of earthquake swarms were detected for more than a week. These clusters of earthquakes were analysed to be between magnitudes of 4.0ML to greater than 6.0ML.Therefore, this study is to investigate the occurrence, the analysis and the interpretation of the earthquake swarm that had occurred before the main shock of the M8.0 at Santa Cruz Islands in the Solomon Islands. The aim of these findings is to determine the earthquake activities that cause the clusters of the earthquake swarms from these three main factors of phenomena, which is the fluid movements, the volcanic magma and the slow slip event of the fault. Earthquake activities are taken from the USGS seismic data and will also use the ORSNET seismic data for assistance from this observation.

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**P1.2 The Solid Earth and its Structure** - Board: 44 / **P1.2-868**

# Comparative Analysis of Pulse-Like Ground Motion Identification and Classification Using Machine Learning Techniques

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The growing interest in pulse-like ground motions, especially occurring near faults, stems from their potential to inflict significant structural damage due to distinct directivity and fling effects. This study seeks to enhance the identification and classification of these impulsive ground motions by integrating traditional data-processing methods with advanced machine learning techniques. Although traditional data-processing methods are effective, they often require intensive calculations. In this research, traditional methods will be utilized to identify pulse-like ground motions, followed by application of Machine Learning techniques for classification purposes. The methodology involves training various classification algorithms on an extensive data set of ground motion records and comparing their performance in identifying pulse-like signals and categorizing them accurately. This study assesses the reliability and accuracy of these models, emphasizing their capability to address the computational challenges inherent in traditional approaches. Experimental results indicate that classification algorithms can reliably identify pulse-like ground motions and predict their pulse periods with high accuracy, offering a viable alternative to conventional methods. This advancement holds significant implications for seismic hazard analysis and earthquake engineering, suggesting that the integration of Machine Learning and conventional methods can contribute to the development of more resilient structures capable of withstanding near-fault seismic events.

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**P1.2 The Solid Earth and its Structure** - Board: 45 / **P1.2-870**

# Ground Motion and Aftershock Seismicity Characteristics following the Mw 6.5 Earthquake in Paphos, Cyprus on 11 January 11 2022

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On 11 January 11 2022, a powerful 6.5 magnitude earthquake struck Paphos, Cyprus, affecting the broader eastern Mediterranean area. Recorded seismic activity at the AKMS station revealed a PGA of 296.496 cm/s² and a PGV of 5.573 cm/s, indicating intense shaking and rapid motion. Ground motion parameters, including intensity, perceived shaking, potential damage, PGA, PGV, and instrumental intensity were used to evaluate the earthquake's impact. Over nearly two years following the event, data collection recorded 693 seismic events with an estimated completeness magnitude (Mc) of 1.4. Analysis using the maximum likelihood method demonstrated a b-value of 0.65 ± 0.09, suggesting the mainshock occurred in a zone of elevated tectonic stress. The aftershock decay rate, with a p-value of 0.73, indicates a quick reduction in stress levels post-mainshock, accompanied by a high frequency of initial aftershocks as shown by a c-value of 5.0. The fractal dimension (Dc) of 1.75 ± 0.01, indicating aftershock clustering along a particular fault line. The analysis exhibited a slip ratio of 0.58, indicating significant slip during the mainshock, with potential implications for future stress distribution. Integrating these findings with geological studies provides deeper insights into fault dynamics, stress distribution, and future seismic activity forecasting.

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# Study on epicenter accuracy based on velocity models acquired from joint inversion

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Seismic location is a crucial problem in event monitoring and the research on improved location accuracy has been driven by efforts to effectively monitor the CTBT. Epicenter location accuracy is affected by many factors, including picking quality of seismic arrival times, accuracy of velocity model and distribution of seismic network. The accuracy of the velocity model will greatly influence the location results when the phase picking error and the geometry of the seismic networks are fixed. With the recent development in seismic imaging methods and accumulation of seismic observed data, a variety of velocity models have been constructed. While some studies focus on analyzing the consistency and reliability of obtained velocity models, few research pay attention to the location accuracy based on different velocity models. To develop more accurate velocity models and systematically assess the location accuracy improvement using different models, we collected seismic datasets from southwest China and conducted joint inversion using body wave arrival times,

surface wave dispersion and receiver functions. A comprehensive evaluation has been performed to compare the location accuracy between the collected velocity models and the newly developed model. The results can provide insights for the application of three-dimensional velocity models in seismic monitoring.

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**P1.3 The Oceans and their Properties** - Board: 16 / **P1.3-056**

## Prototype tsunami database and analysis rupture duration for tsunami earthquake warning in Sumatra

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The issuance of tsunami warnings constitutes a pivotal measure aimed at preserving human life and lessening the impact on local communities. The moment magnitude of the P wave (Mwp) alongside the rupture time duration (Tdur) can be employed as rapid parameters for disseminating tsunami warnings. In this manuscript, we analyze the seismic waveform data sourced from a global network to ascertain Mwp and Tdur pertaining to the South-West Coast of Sumatra earthquake. Mwp is computed through both automatic and manual phase picking of the P phase. The findings of this investigation reveal a well-characterized correlation between the P wave data obtained from both automatic and manual picking methods, as well as between Mwp and the duration of time. Moreover, the results provide promising insights for the development of an early warning system that is projected to be established in the region in the foreseeable future. The data generated from tsunami modeling are securely stored within the database utilizing an array of technological frameworks. The database visualization comprises a map detailing tsunami wave propagation, an animation illustrating tsunami wave movement and information regarding the affected areas, inclusive of location details, estimated time of arrival and estimated wave height.

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**P1.3 The Oceans and their Properties** - Board: 17 / **P1.3-057**

## Tsunami modeling and inundation area from landslide scenario due to the Rokatenda volcano eruption

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The peril associated with the eruption of Rokatenda Volcano is not solely attributed to its eruptive products, but it also possesses the capacity to induce a tsunami. This investigation seeks to simulate the timing of tsunami arrival and its height, as well as to model the inundation effects stemming from a landslide estimation that could precipitate a tsunami following an eruption of Rokatenda Volcano. This research employs the COMCOT (Cornell Multi-grid Coupled Tsunami) software for tsunami modeling purposes. Parameters for the landslide scenarios are developed based on an estimation of the total volume of landslide debris that may be generated during an eruption. The volume ranges from 25 million to 100 million cubic meters. This estimation also incorporates the volume of lava discharged during the eruption. Two distinct directions for the landslide scenarios were determined based on the orientation of the lava flow as delineated in the Rokatenda Volcano Hazard Area Map which is issued by PVMBG. The outcomes from the tsunami modeling encompass a model for the propagation of tsunami waves, as well as calculations for arrival time, height, inundation height and a tsunami hazard map corresponding to the most severe scenario.

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**P1.3 The Oceans and their Properties** - Board: 18 / **P1.3-060**

# Analysis of tsunami hazard potential based on a submarine earthquake scenario M 7.4 in Buleleng Regency, Bali Province

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Research on tsunami potential in northern Bali is rarely conducted. Most of the prior research was conducted in the southern region of Bali island due to its geographical location near the megathrust subduction zone. However, the earthquake-triggered tsunami may occur due to the existence of a Back Arc Thrust (BAT) zone in the north of Bali. A Back Arc Thrust (BAT) zone runs across the northern half of Bali Island and extends to Flores Island. Historically, Based on BMKG tsunami catalog for the period 416-2018, an earthquake-trigerred tsunami occurred in 1815 with an estimated magnitude of M~7.0/~7.3. This earthquake-tsunami event claimed the lives of 10,253 people in Singaraja and Buleleng. To mitigate tsunami risks in Buleleng Regency's coastal areas, a tsunami modeling analysis was conducted using the Tsunami Observation and Simulation Terminal (TOAST) software. The results indicate a Major Warning zone in eastern Buleleng with a 3.43-meter run-up and a 1-minute ETA (Estimated Time Arrival), and a Warning zone in the western part with a 1.921-meter run-up and a 4.5-minute ETA. The population density in areas of eastern Buleleng vulnerable to tsunamis is 2831 people per square kilometer, while western Buleleng has a density of 1683 people per square kilometer.

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**P1.3 The Oceans and their Properties** - Board: 19 / **P1.3-122**

# Subsea Environmental Sensing with Operational Submarine Cables

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We review opportunities afforded by emerging optical submarine cable-based technologies for sensing the marine environment including earthquakes, water waves and explosions. The goal of the submarine fiber sensing Working Group is to enable tsunami early warning based on operational submarine cables. Monitoring changes in water height and temperature in the deep ocean is challenging because deploying and maintaining sensors there is hard. There are more than a million kilometers of submarine telecommunication cables on the seafloor. To take advantage of these cables for geophysics, we developed a new cost-effective technology based on fiber optic sensing techniques that does not disrupt telecommunication service. We applied it to a trans-Atlantic cable between Portugal and Brazil. Comparing the observed signals to predicted ocean tide heights and seafloor temperature variations, we found that the primary reason for our observation of the ocean tidal signals could be the cable stretching and contracting in response to ocean tide pressures, and a secondary factor of strong seafloor temperature variations at shallow depths. Our findings demonstrate the effectiveness of our method for recording seafloor temperature and pressure and suggest it could be broadly useful, given the extensive length of submarine cables. Cooperation with CTBTO opens interesting opportunities.

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**P1.3 The Oceans and their Properties** - Board: 20 / **P1.3-170**

# Acoustic detection of a maritime accident: The case of MOL Comfort

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On 17 June 2013, the container ship MOL Comfort suffered a crack amidships during inclement weather in the Arabian Sea. The ship broke into two sections that sank on 27 June and 10 July 2013, respectively. A triplet of hydrophone station HA08 of the International Monitoring System recorded underwater sound phases associated with the sinking of the two sections. Arrivals derived from progressive multi-channel correlation processing of the hydrophone triplet data match the time and location of both events and must have travelled in the Sound Fixing and Ranging channel of the oceanic water column. Our findings are corroborated by results from long-range propagation modeling. These observations further highlight the exceptional capabilities of the IMS hydroacoustic network and its value for civil and scientific applications.

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**P1.3 The Oceans and their Properties** - Board: 21 / **P1.3-244**

# Propagation of sound from an explosive source placed in a shallow-water wedge or deep water near the ocean bottom

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The predictions made in this paper about sound propagation situations referred to in the title are based on an analysis of the propagation of acoustic wave motion from an explosive point source of a wide spectral range placed in the corresponding benchmark models: a wedge of fluid and a half-space of fluid, each of which is over an elastic solid bottom where the shear-wave velocity is less than the speed of sound in water. In the wedge, source-to-receiver transmission proceeds by repeated reflections; in the half-space, via a single bottom reflection. Using a semi-analytical method of generalized ray, the transmitted wave motion in each model has then been evaluated exactly in the form of an unattenuated signal of three consecutive phases: the phase of the lateral waves, the phase of the source and the regularly reflected waves, and the phase of the Scholte interface waves. When attenuation in the bottom is accounted for, only low frequencies of the source spectrum can propagate over large distances with little attenuation and hence the Scholte-waves phase might dominate at remote receivers. It might then also dominate the propagation in the SOFAR channel, upon entering from a shallow-water wedge or deep water.

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**P1.3 The Oceans and their Properties** - Board: 22 / **P1.3-287**

# Time residuals at HA11 and HA3 for T-phases from deep earthquakes in the Ring of Fire

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This work investigates the T-phase time residuals (defined as differences between the observed arrival times and their theoretical values) at IMS hydrophone stations HA11 and HA3 in the Pacific Ocean. The work is focused on T-phases from earthquakes in the Ring of Fire recorded between 2001 and 2024. Time residuals of T phases from these regions can typically range from minus 150 to 150 seconds. These disparities between expected and observed arrival times can present significant challenges when associating hydroacoustic signals to events built by automatic processing systems or by human analysts based on signals recorded by the IMS network. In this work, we shed light on the reasons for these high time-residual variabilities. We show that the time residuals in these regions depend on the location of the hypocentre along the subduction plate. Overall, time residuals go from negative (T phases arrive earlier than expected) to positive (later than expected) as the earthquake depth decreases along the subduction and approaches the Ocean Trench. We present general results for the Ring of Fire and detailed analyses for regions with different subduction angles in the trenches of Kermadec-Tonga, Mariana, Philippines, Nansei-Shoto, Kuril, Aleutian and Peru-Chile.

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**P1.3 The Oceans and their Properties** - Board: 23 / **P1.3-405**

## Detecting Seismoacoustic Events in the Arctic Ocean

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Rapid changes to the Arctic Ocean impact its acoustic environment. As the Arctic warms, the soundscape is modified by changes to the thermohaline stratification of the water column as well as changes in the distribution and morphology of sea ice. Sea ice attenuates sound through scattering and absorption, emits sounds as it deforms and exerts control over the generation of sea surface waves and the distribution of sound-producing marine wildlife populations and industrial activity. Geophysical modeling and sensing on seasonal and decadal scales are needed to track changes in the Arctic soundscape and their impacts on our ability to detect sound sources of interest. We examine changing propagation and noise conditions in the Arctic Ocean using projections from the US Department of Energy's Energy Exascale Earth System Model (E3SM) and in situ data from the Beaufort Sea including passive recordings from a National Oceanic and Atmospheric Administration (NOAA) hydroacoustic station and an active acoustic experiment. We present progress toward understanding ice-affected acoustic propagation in parts of the Arctic as well as mapping seasonal sound patterns recorded at the NOAA hydrophone. Moreover, we evaluate the impacts on our ability to detect underwater acoustic sources arising from the evolving Arctic Ocean environment.

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**P1.3 The Oceans and their Properties** - Board: 24 / **P1.3-428**

## Assessment of Earthquake Depth Indicators from Hydroacoustic Analysis of T-Phases

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Depth assessment is one of the most difficult, however, most effective event screening methods and is usually achieved by the International Monitoring System using seismic sensors. Analysis of waveforms recorded at hydrophones from a small set of events with similar mechanisms and

relatively high SNR, located in Central Sumatra, indicated promising depth sensitivity and dependency of T-phase signal properties. Specifically, the T-phase time residuals, the rise time, the dominant period, duration, time-dependent spectral content and the envelope width showed systematic depth dependency. We assess the operational value of these findings through investigations of the above-mentioned parameters at other locations, while considering station-event configurations, event mechanism and event signal–to–noise ratios.

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**P1.3 The Oceans and their Properties** - Board: 25 / **P1.3-659**

## Automatic identification of sources detected by the hydroacoustic stations of the International Monitoring System

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The low attenuation in seawater and the low-velocity layer SOFAR (Sound Fixing and Ranging) channel enable the hydroacoustic stations of the International Monitoring System (IMS) to record acoustic waves over long distances. The French National Data Center uses the Progressive Multi-Channel Correlation (PMCC) method to detect low-frequency coherent waves (< 40 Hz). These detected underwater acoustic waves are emitted by various sources (e.g. earthquake, volcanism, cryosphere, whales, airgun, anthropophonic explosion). High-amplitude PMCC detections can be associated with one type of these sources with DTK-Diva, but their revision is not systematically carried out by an analyst. We present here a method to discriminate these detections by source type. We analyze recordings from hydrophone triplets in the Atlantic (HA10), Indian (HA1, HA4, HA8) and Pacific (HA3, HA11) oceans over the period from January to December 2023. This represents 111,233 detections with a maximum amplitude above 1 Pa. We train a convolutional neural network and calibrate it using conformal prediction. On average, 75 ± 6% of detections are associated with one source type with a confidence level of 95%. A consolidated event catalogue would enhance the discrimination performance of the classifier by source type.

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**P1.3 The Oceans and their Properties** - Board: 26 / **P1.3-766**

## Acoustic Propagation Modelling on the Cloud

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The computation of 3D acoustic models for long-range propagation in realistic oceanic environments poses significant computational challenges. Here, we present an extension of our GPU-accelerated hydroacoustic transmission loss solver in Julia. This work is built upon a model previously developed by us, enhancing its capability to run in cloud environments with large-memory GPU instances. It is based on the parabolic wave equation and the Split Step Fourier method. The extended solver can resume long computations that were interrupted, enabling it to leverage interruptible (spot) nodes thus reducing computational costs. Preliminary tests confirm that this approach indeed enables resolutions, swath widths, frequencies and propagation distances previously unattainable on our standard desktop systems, significantly reducing the need for substantial capital investments in dedicated HPC resources. We illustrate this with a case study involving a propagation distance of 10,000 km. This work is intended to lower barriers to large-scale hydroacoustic research by enabling analyses of more detailed scenarios and providing a flexible and cost-effective solution for diverse applications in underwater acoustics research, potentially aiding in aspects such as the detection and analysis of underwater acoustic events like those monitored by the IMS.

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**P1.3 The Oceans and their Properties** - Board: 27 / **P1.3-815**

## Comparative analysis of recent and historic low-frequency acoustic propagation from the island of Kauai to hydrophones at Wake Island: implications for accurate localization of impulsive signals

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A low frequency sound source, deployed in the mid-1990s off the North Coast of Kauai at deep sound channel axis, provides a critical tool for measuring the deep ocean temperature across North Pacific Basin. This temperature measurement is enabled by precisely timed transmissions from a cabled sound source and their reception on distant cabled hydrophones. We focus on hydrophone receptions at Wake Island, specifically HA11N and HA11S of the International Monitoring System (IMS) and WK30 and WK31 stations from the Prototype International Data Center (PIDC). These historic and ongoing transmissions have built up a 30-year record of travel-time, revealing a trend of quickening propagation and thus warming of the deep ocean sound channel in the subtropical mid-Pacific Ocean. Models of acoustic propagation generate a sensitivity kernel to infer deep ocean temperature from travel-time measurements. These acoustically derived measurements, compared to ocean state estimates informed by non-acoustic satellite measurements and drifting profilers, highlight the uncertainty in deep ocean temperature and the implication on impulsive source localization.

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**P1.3 The Oceans and their Properties** - Board: 28 / **P1.3-851**

# Interpretation of whales diving behaviour in the vicinity of IMS hydrophone triplet.

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Whale signals are frequently observed at triplets of hydrophones of the IMS hydroacoustic stations. Fin whale signals emit characteristic time-frequency patterns. Two types of fin whale signals are observed at IMS stations HA11, located close to Wake Island in the Pacific Ocean. Echoing of the signals is clear on the recorded traces and attributed to multiple bottom and sea surface reflections. Differential move-out between the direct arrivals, sea bottom and surface multiple reflections are modelled and interpreted as indication of the depths reached by the animals within a single dive. The waveforms resulting from the complex interaction between the direct signal and surface and sea bottom reflections signal are modelled. These observations and techniques provide a harmless way to record abundant observations of the animals' diving behaviour and should help biologists in interpreting the time statistics and variations of the diving behaviour.

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**P1.3 The Oceans and their Properties** - Board: 29 / **P1.3-864**

# Potential tsunami disaster from volcanoes in Indonesia

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Indonesia is at the forefront of earthquake and tsunami disasters due to tectonic and geological complexity. Non-seismic tsunamis caused by landslides and volcanic collapses have become an important new disaster issue in Indonesia since the 2018 Palu and 2018 Sunda Strait events. Based on VSI-ESDM (2024), a dozen active volcanoes were found on the coast and under the sea. Mount Gamalama is an active volcano in the Ternate region, North Maluku. Based on reports from Gamalama volcano monitoring officers, the potential for eruptions and landslides occurred following events in 2011 and 2012 where lava flows headed east. To carry out tsunami modeling, numerical modeling techniques can be used. Studying the nature of sea water motion requires a marine hydrodynamic model. We use the Cornell Multi-grid Coupled Tsunami (COMCOT) model which is based on the Shallow Water Equation (SWE) (Wang and Power 2011). We use national bathymetric maps with medium resolution. We took benchmark GPS stations and initial tide stations. Based on landslide scenario tsunami modeling, the results obtained were that a small portion of the caldera collapse on the northeast side resulted in a large tsunami as high as 11 meters.

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**P1.4 Multidisciplinary Studies of the Earth's Subsystems** - Board: 1 / **P1.4-241**

# Real Time Global Assessment of Tsunami Risks Using Acoustic Gravity Waves

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This study presents a real time technology for detecting and classifying geophysical events using acoustic signals. Initially developed for tsunami monitoring, the system integrates advanced computational models and machine learning algorithms to process acoustic data and extract event characteristics, including location, magnitude and fault dynamics [1]. The methodology facilitates real time mapping of risk areas and event trajectories, providing timely insights critical for effective response strategies. Validation against historical events demonstrates robust performance, with global scale analyses completed within seconds on standard multi-core machines. An additional feature of this technology is its potential applicability to a wider range of geophysical events, such as underwater explosions and other seismic activities. Its flexibility positions it as a complementary tool for existing warning frameworks, with possible relevance for organizations like the Comprehensive Nuclear-Test-Ban Treaty Organization in future monitoring efforts. By addressing key challenges such as false alarms and response delays, this system contributes to improving global event monitoring and enhancing disaster preparedness. It provides a valuable resource for decision makers aiming to mitigate risks and ensure public safety.

[1] Kadri, U., Abdolali, A., and Filimonov, M.: GREAT v1.0: Global Real-time Early Assessment of Tsunamis, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2024-139, in review, 2024.

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**P1.4 Multidisciplinary Studies of the Earth's Subsystems** - Board: 2 / **P1.4-254**

# Unveiling Hydroacoustic Signatures of Aircraft Crashes: Insights from the MH370 Case

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Aircraft crashes into oceans generate unique hydroacoustic pressure signals detectable across vast distances. This study leverages data from the Comprehensive Nuclear-Test-Ban Treaty Organization's hydroacoustic network to examine the acoustic signatures of historical aircraft incidents. Specifically, the analysis revisits the disappearance of Malaysia Airlines Flight 370 (MH370) and explores the plausibility of its crash leaving discernible signals at hydrophones. Through systematic analysis of acoustic signals during MH370's final trajectory, plausible signals were identified within the expected time and spatial parameters. Challenges in detection, such as bathymetric barriers and noise interference, underscore the complexity of analysing such events. To validate findings, this

study proposes controlled explosion experiments mimicking the energy release of a high impact crash. The findings highlight hydrophones' potential in detecting long distance acoustic signatures, offering a novel approach for crash investigation in oceanic environments. By advancing our understanding of acoustic signal propagation, this research provides critical insights into MH370's unsolved mystery while contributing to the development of methodologies for analysing comparable incidents. The proposed experimental framework offers actionable recommendations for enhancing future search and rescue operations.

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**Online e-Poster Session 2** - Board: 0 / **P1.4-380**

## Evolution of signals of aerosol variations, rock temperature, and crustal deformation in the far tunnel of the Baksan Neutrino Observatory during strong earthquakes In Turkey on 6 February 2023

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Since 2004, a unique underground geophysical laboratory has been equipped at the Baksan Neutrino Observatory (BNO) at a distance of about 4 km from the mouth of the tunnel. A complex of scientific equipment was installed in the laboratory, which allows continuous studies of fluid activity, deformation processes, weak seismicity, as well as studying temperature anomalies within the Elbrus volcanic center. The underground geophysical laboratory successfully operates geophysical information and measurement systems that have no analogues in the world, providing registration of deformation, seismic, temperature and magnetic variations in conditions of minimal natural interference. Recently, we discovered a correlation between the signals of a laser deformograph, a laser lidar measuring the density of aerosol variations and the temperature values inside the rocky base in the dead-end tunnel of the BNO, at the time of both strong earthquakes in Turkey (6 February 2023), which had almost identical magnitudes of 7.8 and 7.7. An estimate of the radius of the stress zone from the epicenters gives a value of about 2000 km, which exceeds the distance to the BNR tunnels (about 900 km) and, thus, allows for variations in the stress-strain state in the signals of the deformograph, thermometer and lidar.

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**P1.4 Multidisciplinary Studies of the Earth's Subsystems** - Board: 3 / **P1.4-518**

## Seismic Signature of the 25 August 2024 Nqweba Meteorite, Eastern Cape, South Africa

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On 25 August 2024, at approximately 06:50 UTC, several stones from an achondrite meteorite fell around the town of Nqweba, Eastern Cape, South Africa, following a widely observed meteor fireball and detonation. The infrasound station I47ZA, located in Boshof, South Africa (about 590 km north-northeast of Nqweba), detected an atmospheric disturbance generated by an energy release between azimuths 180° and 200°, roughly towards Nqweba. This study analyses seismic signals recorded at three seismic stations in the region of the sightings to detect seismic signatures from the meteorite's atmospheric entry. Clear seismic arrivals were observed at stations SVILL (10 km from Nqweba), BUFB (100 km), and BFKLF (195 km) at 06:53 UTC, 06:54 UTC, and 06:57 UTC, respectively. The seismic signals exhibited a two-stage pattern typical of meteor-related events. The first arrival, the air-coupled ground wave, is a train of dispersive Rayleigh waves generated by shock waves interacting with the ground. The second arrival, a stronger W-shaped pulse, is the directly-coupled airwave, corresponding to a positive overpressure from a ballistic shock. This secondary arrival will be used to constrain the meteorite's trajectory through arrival time, particle motion, and polarization analyses.

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**Online e-Poster Session 1** - Board: 0 / **P1.4-630**

## Tectonic stress field in the Valley of Mexico from local seismicity

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We performed a comprehensive analysis of the seismic activity in the Valley of Mexico using the records of the nearby seismic stations. We determine the focal mechanisms of earthquakes (M > 2.5) in the Mexico Basin from 2010 to 2024. Events were chosen with a high signal to noise ratio, i.e., raw P and S arrivals clear enough to be distinguished. Focal mechanisms were inverted using the ISOLA method, finding that most of the seismicity of the Valley of Mexico presents normal-type faulting. We grouped the resulting events according to their epicentral location into five families that we will call: a) Sierra de las Cruces (SC) b) Central area (C) c) Southeastern area (SE) d) Lake-bed area (LB) and e) Sierra Chichinautzin (CH). With these five event groups, we performed a local stress field analysis to detect variations that allow us to infer how these stresses affect the activation of previously mapped faults. Most activity occurs mainly in the western areas, along the Sierra de las Cruces and southeast of the Valley of Mexico, in Milpa Alta and Juchitepec zones. This result is significant because the activity in the center-west part represents a danger due to its shallow depth under highly populated areas.

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**P1.4 Multidisciplinary Studies of the Earth's Subsystems** - Board: 4 / **P1.4-772**

## Utilization of the Auxiliary Seismic Station APG (AS37) for the Analysis of Seismicity Induced by Tropical Depressions Eta and Iota in the Karst Region of Northern Guatemala

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The 2020 Atlantic hurricane season was one of the most active on record, with tropical storms Eta and Iota causing widespread disasters in Nicaragua, Honduras, and Guatemala. These storms triggered floods and landslides in Guatemala, leading to fatalities, disappearances, and significant damage to housing and livelihoods, exacerbating a humanitarian crisis already strained by COVID-19 restrictions. During and after the storms, the Red Sismológica Nacional (RSN), operated by INSIVUMEH in Guatemala, recorded seismic activity triggered in the departments of Alta Verapaz and Quiché, both severely affected by flooding, increasing public concern. The APG station (AS37) in Baja Verapaz (south of the epicenters) was critical for monitoring most of these events. This study explores the relationship between the seismicity and regional floods, highlighting the karst geology and complex hydrogeological systems. Documented studies in similar geological environments in Europe attribute such seismicity to sudden flooding, pore pressure changes, and diffusion processes, consistent with the temporal evolution of the observed seismicity. The spatial distribution of epicenters and correlation analyses of earthquake families from two nearby seismic stations suggest the activation of minor seismic sources, resembling cases of artificially induced seismicity. This marks the first instrumental analysis of meteorologically induced seismicity in Guatemala's karst environments.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 1 / **P2.1-161**

## Investigating Seismic Source Characterisation Using P/S Amplitude Ratios at Local and Near-Regional Distances: A United Kingdom Case Study

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Characterisation of seismic sources, including earthquakes and explosions, is of interest to the nuclear-test-ban verification community. At local to near-regional distances (≤300km) signals from quarrying, mining and controlled explosions are commonly observed in addition to earthquake seismicity. We investigate the ratio of *P*- to *S*- wave amplitudes as a seismic source discriminant for events located and recorded in the UK. This *P/S* discriminant has previously had mixed results in other regions at local distances (≤200km) (Pyle & Walter, 2019; Wang et al., 2020). We formulate methods to

calculate *P/S* ratios from local observations of UK seismic events. Root-mean-square displacement amplitudes are measured at single 3-component stations, corrected for geometrical spreading then averaged across the network, accounting for signal attenuation along the unique source-receiver paths. We observe that network-averaged *P/S* ratios discriminate between UK earthquakes and explosive sources, with higher *P/S* for explosions than earthquakes. The results are in agreement with previous empirical observations from elsewhere and our current understanding of explosion source spectra: explosions generate proportionally less *S*-wave energy than earthquakes. The greater discrimination power at high frequencies (>8Hz) could be in part due to the difference between *S*- and *P*-wave corner frequencies.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 2 / **P2.1-174**

## Examining the potential for detecting simultaneous noble gas and particulate samples in the IMS RN network

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Given the existing radioxenon and radioaerosol backgrounds encountered by the IMS, detections of multiple isotopes are useful for screening purposes. We examined this issue by using six UNE release scenarios, including fractionated ones based on the literature, and subsequent atmospheric transport to IMS stations. The study identifies those radioisotopes (radioxenon and particulate) that are most likely to be detected on their own and as part of simultaneous noble gas and particulate detections, thus informing radionuclide data fusion efforts on the types of events that might be expected. Methodology will be described and results presented.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 3 / **P2.1-225**

## Leveraging the OSIRIS-REx Sample Return Capsule re-entry for infrasound detection of atmospheric events

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The re-entry of NASA's OSIRIS-REx Sample Return Capsule (SRC) into Earth's atmosphere in 2023 provided a unique opportunity to detect and analyze infrasound generated by a controlled atmospheric entry. As the SRC traversed denser atmospheric layers at hypervelocity, it produced shock waves that decayed into acoustic signals. The strategic placement of ground-based and airborne sensors along the SRC's trajectory enabled the detection of signals from a substantial portion of the object's path. This data set offers an unprecedented foundation for refining atmospheric entry and shock wave propagation models. The well-defined parameters of the SRC (mass, size, velocity) allowed for comprehensive analysis, validating the critical role of acoustic monitoring in characterizing high-altitude phenomena. The findings in this study can be leveraged for differentiating anthropogenic atmospheric events from natural meteoroid and asteroid entries. Furthermore, the results demonstrate the strategic value of infrasound within regional and global monitoring systems, including those used for the CTBT, for detecting and characterizing atmospheric events of both natural and human origin.
SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 4 / **P2.1-229**

## Assessing energy estimation methods for bolides in atmospheric monitoring

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Bolides, or exceptionally bright meteors resulting from the atmospheric entry of asteroids or meteoroids typically over 10 cm in diameter, provide significant infrasound sources for global monitoring efforts. Originating from cometary or asteroidal fragments, these objects enter Earth's atmosphere at hypervelocity, generating shockwaves that decay into low-frequency (<20 Hz) sound or infrasound, detectable globally. Bolide events offer valuable opportunities for refining infrasound-based energy estimation methods. Current empirical relations, initially developed for stationary anthropogenic explosions, are applied to estimate bolide energy, yet these methods are not specifically tailored for natural atmospheric entries. In this study, we take a systematic and holistic approach by analyzing nearly 1,000 bolides from the NASA JPL CNEOS database, focusing on ~300 cases with comprehensive velocity and light curve data. By examining a broad parameter space, we compare period- and amplitude-based methods and evaluate infrasound signal parameters in relation to physical characteristics. Our refined period-based energy relations aim to advance bolide yield estimation, contributing to capabilities in atmospheric monitoring and bolide characterization.
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**P2.1 Characterization of Treaty-Relevant Events** - Board: 21 / **P2.1-238**

# The NPE2024 event analysis and characterization at the Kenyan National Data Centre (KE-NDC)

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During the SnT2023, Mulwa and Dindi (2023) presented case examples of systematic seismic events discrimination methods at KE-NDC. The results were subsequently published in Pure and Applied geophysics journal (see Mulwa, 2024 in PAGEOPH, https://doi.org/10.1007/s00024-024-03458-4). The NPE2024 entailed a request by the State of "Andlantis" for Expert Technical Analysis (ETA) of potentially CTBT-relevant event in the State of "Bezores". Andlantis provided "CTBT Member State" with SHI data from her National Technical Means (NTM). At KE-NDC, seismic waveform data was subjected to analysis using SHI NDC-in-a-Box. Based on preliminary event location, the epicenter was at latitude 41.0872oN and longitude 27.9954oS. The origin time of the event was 20240114 06:19:36.36 (as per Andlantis time zone, UTC-2). Using this preliminary location, IDC REB product was screened at KE-NDC for possible triggering event. In order to determine compliance/non-compliance of CTBT by "Bezores", the triggering event was subjected to the following discriminants: focal depth, mb:Ms and focal mechanism (Mulwa, 2024). Additional discriminant used was the frequency content of hydroacoustic signal at H10N. The results showed that "Bezores" had not violated the CTBT. Further discussions of the methodologies will be presented during the SnT2025.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 6 / **P2.1-258**

# Characterizing near-source physical parameters of buried explosion sources using deep learning

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Characterizing seismic sources is critical to accurately constraining important seismic source features of interest. Many factors affect seismic far-field waveforms (FFWFs) used for source characterization, including physical characteristics near the source, such as emplacement or ground material properties. How near-source characteristics and the methods with which we estimate source features affect FFWFs, however, is poorly understood, especially when considering near-source, nonlinear effects. We present our progress in developing deep learning methods to characterize near-source characteristics, including emplacement, ground material, yield strength, and fracture pressure. We outline our workflow for training data generation, where we use a nonlinear shock physics code coupled to a linear wave propagation code to simulate buried chemical explosions and the FFWFs they generate at the local scale (<~700 m distance). We vary numerous factors, including source depth, chemical explosion size, and receiver locations, in addition to the physical near-source characteristics we aim to characterize. We demonstrate success in our preliminary development of deep learning models for near-source characterization of emplacement, ground material, yield strength,

and fracture pressure, and we discuss potential areas for improvement.
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**Online e-Poster Session 1** - Board: 0 / **P2.1-285**

## Electromagnetic signatures of underground chemical explosions

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Electromagnetic signatures from the Low Yield Nuclear Monitoring PE1 Shot A conducted in October 2023 at the Nevada Nuclear Security Site have been analyzed. The data show signals from the hot, expanding plasma in the Earth's natural magnetic field and from seismo-electric mechanisms. However, the polarization signatures of the prompt signal do not match predictions from a simple "magnetic bubble" mechanism. The implications of the mis-match between the model and the measurements are examined and the consequences for future experiments are assessed.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 7 / **P2.1-308**

## Nuclear event timing with three-dimensional spatial analysis of radioxenon isotopic activity ratios

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The three-dimensional (3D) spatial analysis of radioxenon isotopic activity ratios is a powerful approach for the determination of the time of a nuclear event. In contrast to the 2D planar analysis, this method requires at least a triple detection from the same sample among the four CTBT-relevant radioxenon isotopes, which are 131mXe, 133mXe, 133Xe, and 135Xe. One method of the 3D spatial approach applies a virtual time axis. This starts from an imaginary zero point and is used for determining the age by taking decay into consideration. For any measurement entered in the 3D plot time zero can be determined by projecting it on this virtual axis, if it would be caused by a nuclear explosion. The valid range of the virtual time axis is determined by requiring the angle alpha ≤ 0.1°

and for a relative age error ≤ 10%. A more sophisticated method can avoid the age error and be applicable for the whole age range. This uses the trajectories of nuclear explosion scenarios in 3D space rather than a virtual time axis. The age of any data point is determined by a perpendicular projection on the nuclear explosion trajectory.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 8 / **P2.1-391**

## Yield and Depth of DPRK Explosions Inverted from Regional Seismograms Using a New Algorithm

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A new method to invert regional seismograms had recently been presented to extract the yield and depth of explosions which are accompanied by contributions from both double couple (DC) and a strong compensated linear vector dipole (CLVD) source (presented in this conference by Saikia). In this paper, we are applying this approach to investigate the reliability of the yield and depth of the DPRK sources and compare the results with those published in several journal papers. Following the yield estimation and moment extractions for the CLVD and the DC sources, we combined them to construct a full moment-tensor matrix which is then analyzed using the algorithm of Tape and Tape (2019) as a representation on the Lune plot. In this study, we further investigate the effects on inferred source parameters due to the uncertainty in the velocity model, location of the explosions and the possible error in the origin times. An added aspect of this study is to test the effectiveness of this method against the method recently published that uses the Bayesian inference method (Chiang et al., 2024).

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 9 / **P2.1-443**

## Quantifying uncertainty in regional-scale seismic moment tensors

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Seismic moment tensors are a fundamental tool used to characterize events of interest to the nonproliferation community. Understanding and quantifying the uncertainty in moment tensor solutions are key to that characterization task. There are many sources of uncertainty confounding the accurate recovery of moment tensors, including imperfect knowledge of Earth structure between the source and receivers and low signal to noise ratios, as well as in the methods used, such as first motions, P- and/or S- amplitude picks, up to full waveform inversions. Earth models used in source inversions range from 1-D global to regional-scale models through 3-D regional tomographic models with varying degrees of fidelity and resolvability. We will present quantitative results of a synthetic study of the uncertainty in the recovery of seismic moment tensors by including sources of error from Earth models, noise, and the techniques used to solve for the moment tensors. The effects of realistic noise are evaluated by using noise models based on earthquakes at a regional scale. We also explore how inaccurate Earth models, as well as how differing assumptions and data used in moment tensor inversions, affect seismic source models.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 10 / **P2.1-471**

## Applying Radioxenon Isotopic Ratio for Nuclear Explosion Monitoring: Determination of Origin Time

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The isotopic ratio of radioxenon is crucial for distinguishing between civilian sources and nuclear explosions. This study focuses on using the Xe-135/Xe-133 ratio to precisely determine the origin time of detected radioxenon. Due to the shorter half-life of Xe-135 compared to Xe-133, this ratio decreases over time, serving as a reliable indicator for estimating the sample's age.

At the initial release, the ratio is approximately 2, consistent with the expected fission yield, providing a solid reference for analysis. Observed data indicate that most radioxenon detections occur between 20 and 60 hours after release, a critical timeframe for nuclear explosion monitoring and verification.

By refining isotopic ratio interpretation, this method improves the ability to assess the timing of nuclear events, supporting global treaty verification efforts. Future work will focus on enhancing detection sensitivity and integrating this approach into international monitoring systems.

These findings will be summarized using box-and-whisker plots to highlight outliers and the isotopic ratio decay curve to illustrate the temporal evolution.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 11 / **P2.1-548**

# Infrasound from rocket launches and reentries observed at the IMS

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Rocket launches and reentries are powerful atmospheric noise sources detectable at infrasound arrays in thousands of kilometers distance. Recorded signatures originate from the ignition, launch, supersonic movement, stage separation and reentry of rockets within the first about 100 kilometers of altitude of the atmosphere. We use IMS infrasound data to localize and characterize these events all over the world.

During the last 20 years, an increasing number of annual space missions was conducted from various globally distributed space ports. These missions were mainly launched to inject satellites in Earth's orbit, but also for space station flights and the exploration of the Moon and other bodies in the solar system. In this context, an increasing number of infrasound events related to rockets was also identified in IDC bulletins.

We investigate and present infrasound detections of interest, including NASA's Artemis 1 Moon mission using the Space Launch System in 2022, SpaceX's orbital flight tests of Starship starting in 2023 and ESA's first launch of the new Ariane 6 rocket in 2024. Furthermore, we highlight a systematic analysis of infrasound recorded from multiple, regularly launched vehicles like Ariane 5, Falcon 9, and various Soyuz and Long March rocket types.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 12 / **P2.1-554**

# Modelling complex P-wave seismograms from the 28 May 1998 Pakistan explosion

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On 28 May 1998, Pakistan detonated its first nuclear explosion. The teleseismic P-waves from this seismic disturbance are complex compared to those typically observed from underground explosions. We observe a spatial correlation between waveform simplicity and take-off angle; with the most simple seismograms being recorded at small take-off angles at the source ($\Delta < 15°$) and at stations clustering to the south and southeast of the focal sphere.
The complex P-waves do not seem to be due to source complexity, scattering in the upper mantle and/or crust beneath the receiver or by an aftershock triggered immediately after the explosion. Instead, the most likely mechanisms generating the observed complex waveforms are the geological

structures and surface topography in the vicinity of the detonation point.
To model the observations, we couple the global wave-propagation solver AxiSEM3D with an arbitrary three-dimensional solver of choice (in this work we use SW4) and thus embed a heterogeneous three-dimensional domain within a spherically symmetric Earth model around the source. Using these hybrid simulations, we explore the effect of near-source geology and surface topography on the complexity of teleseismic waveforms.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 13 / **P2.1-555**

## Moment Tensor Inversion Analysis of DPRK6 Nuclear Events Using CTBTO/IMS Data

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The global verification system under the Comprehensive Nuclear-Test-Ban Treaty (CTBT) is designed to detect all nuclear explosions on Earth, with seismic monitoring relying on the International Monitoring System (IMS) to identify explosion signals. This study applies Moment Tensor (MT) inversion analysis to assist States Parties through expert technical analysis (ETA) of IMS and additional datasets provided by the requesting State. MT inversion determines parameters such as total seismic moment, focal mechanism and source depth, with this analysis focusing on data from declared nuclear events in the Democratic People's Republic of Korea (DPRK), particularly the DPRK6 event on 2017/09/03. Two methodologies were applied: a time-domain regional moment tensor inversion (Dreger 2003) and a joint inversion combining regional waveforms and teleseismic first-motion polarities (Chi-Durán et al. 2024). Using four regional waveforms and 81 teleseismic polarities, and modeling with regional velocity models (Ford et al. 2010), the TDMT approach revealed a predominantly isotropic mechanism with a minor double-couple component, consistent with prior studies (e.g. Alvizuri and Tape 2018; Chiang et al. 2018). The joint inversion further improved the waveform fit, confirming isotropy as the dominant source characteristic. Ongoing efforts aim to incorporate teleseismic waveforms to refine the depth and other characteristics.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 14 / **P2.1-601**

## Generative Neural Networks in Nuclear Test Monitoring

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Various nuclear test monitoring techniques require numerous waveforms and expect good spatial coverage of seismic source. The examples, inter alia, are master-event based location and event discrimination, needing data augmentation due to class imbalance and synthetic seismogram simulation can make a job. Generative Networks (GN) are a novel way of producing realistic, high-quality synthetic seismograms.
Here, we mostly concentrate on the waveform's generation for the master-event based location. For the single component data, we use conventional temporal GN. For multicomponent seismic data, we adopted some multivariate representations of the neural network, which can treat such data simultaneously, considering neural network as multidimensional object, like hypercomplex-valued networks with 4D neurons. Hypercomplex Generative Adversarial Networks (QGAN) and Variational Autoencoders (QVAE) are the variants of generative networks that uses quaternion-valued inputs, weights and intermediate representations. In hypercomplex-valued time series, the components are intrinsically tied together by the algebraic rules of the hypercomplex domain (e.g. quaternion or octonion multiplication rules). These relationships make hypercomplex representations particularly useful for modeling phenomena with inherent coupling between dimensions, while quaternionic convolution in QCGAN are less resource-demanding than their non-quaternionic counterparts, with four times smaller parameter set size. Transformer-based multivariate models are also considered here.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 15 / **P2.1-642**

# The challenging multi-technology scenario of the NPE 2024

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The National Preparedness Exercises (NPE) are held regularly to practise analysis and test procedures within the NDCs and in exchange with the IDC. The German NDC has been organising the NPE series since 2007. The NPE 2024 was announced by the fictitious NDC Andlantis in the NDC Forum. Key elements of the information released included:
- National seismic data in a rather unusual format without event information, e.g. an REB event they refer to;
- National infrasound detections on islands, which had to be found using satellite imagery;
- A reference to real hydroacoustic IMS detections;
- A reference to potentially related IMS samples containing elevated xenon-133;
- Later, mobile national xenon measurements with an additional isotope.

This presentation will show the links between the exercise scenario and the real world of IMS, and the ideas and events that the NPE team had in mind. In particular, the exercise focused on studies typical of expert technical analysis. The exercise highlighted the potential obstacles of dealing with foreign data in a politically unstable environment.

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**Online e-Poster Session 1** - Board: 0 / **P2.1-674**

## Signals of Explosions in Earthquakes: Case Studies with Spotlight Detectors

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In 2012, the National Research Council concluded that earthquake signals cannot effectively mask those produced by explosions. We test that conclusion with multi-channel correlation detectors (correlators) that use records of ground motion (templates) sourced by explosions to detect smaller signals from similar, collocated sources. Our test applies these detectors against thousands of signals with a waveform injection method. This method amplitude-scales a template waveform over a grid of amplitude values, adds these waveforms into a target data stream at times that create interference with background seismicity and processes their sum with a correlator. We apply this method to explosion templates sourced in Nevada state (USA) and recorded by the multi-channel array NVAR. Our study thereby compares correlator performance when we deliberately inject templates into earthquake signals, relative to baseline operation that processes target waveforms injected into data that is absent of known seismicity. We find that a correlator that uses an explosion-sourced template, and that can reliably detect a 1.7 ton, shallowly buried explosion in background noise (a 0.97 detection rate), is unlikely to detect the same event in noisy earthquake interference (a 0.37 detection rate). We thereby demonstrate that earthquake seismicity can hide explosion signals.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 16 / **P2.1-685**

## Characterizing seismic events in a noisy urban and industrial environment

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Urban environments present unique challenges for seismic event monitoring and discrimination. Persistent anthropogenic noise can reduce the signal-to-noise ratios of seismic events and impulsive man-made events can falsely trigger detection algorithms. One approach to improving our monitoring algorithms—to accommodate diverse detection environments—is to incorporate more dynamic anthropogenic noise as training data. Here, we present a dataset of anomalous anthropogenic events detected in a unique urban and industrial environment in the Chicago area. We analyze data from

a broadband seismometer, located within a few kilometers of quarrying operations, a flood-control reservoir, highways and dense residential districts. Applying both traditional (STA/LTA) and a state-of-the-art machine learning detector (EQTransformer) to the station's data generated a high false positive rate (>50%). To characterize these false positives and build a labeled dataset of events, we developed a semi-automated approach to cluster seismic events in two years of continuous data. We will present our methodology, which incorporates a power spectral density detector and K-means clustering. Our approach successfully identified several classes of signals, including high-amplitude quarry blasts, low-amplitude and low-frequency blasts, industrial machinery operations, and blast-like events of unknown sources. We will present example waveforms of these clusters and discuss potential sources of unknown events.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 17 / **P2.1-716**

## Estimating Explosion Yields Using Fourier Neural Operators and Long-Range Infrasound Observations

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Understanding the propagation of long-range acoustic waves is a cornerstone of infrasound research, yet solving the wave equation remains a computationally intensive challenge. This complexity is further exacerbated by the need for recalculations whenever the sound speed structure or source characteristics change. In this study, we present an innovative application of the Fourier Neural Operator (FNO), a cutting-edge machine learning technique, to address these challenges. Specifically, we leverage the FNO for yield estimation from infrasonic observations over distances of hundreds of kilometers. The FNO is trained to predict statistical transmission losses using atmospheric specifications provided by ECMWF and propagation simulation tools developed at CEA. The transmission losses are combined with an explosive source model to estimate the near-source spectral characteristics of explosive events within a Bayesian framework. A comprehensive sensitivity analysis was conducted to optimize the FNO's hyperparameters, providing insights into their influence on the results. Furthermore, we evaluate the impact of various gradient-based optimizers and their combination, on yield estimates and associated uncertainties. This approach is demonstrated with infrasound signals recorded at distances of several hundred kilometers from the Hukkakero military range, where extensive ammunition destruction activities over the past decade have generated a rich dataset of explosive events.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 19 / **P2.1-797**

## Bayesian joint localization and characterization of infrasound events

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Localization and characterization of nuclear detonations can be accomplished using various observation techniques, including seismic and infrasound data. In both cases, accurate knowledge of the propagation medium - specifically, Earth's subsurface and atmospheric properties - is essential for reliable inversion results. This study introduces a joint inference framework designed to localize and characterize events while simultaneously estimating the properties of the wave propagation medium and quantifying associated uncertainties. We apply this methodology to the 2018 meteorite explosion over the Bering Sea, a widely studied event. Our reanalysis leverages a full waveform linear model to address the limitations of empirical models identified in previous studies. To estimate the source and medium parameters, we use a polynomial chaos-based surrogate model to efficiently explore the parameter space. Our results demonstrate that this approach effectively reduces overconfidence in the quantities of interest by providing a robust estimate of uncertainties. In this work, we combine Bayesian inference and recent developments in metamodeling to update the posterior PDF describing the event localization and the associated yield. The difference with the Monte Carlo method lies in the fact that the sampling is carried out over the metamodel, which is built from an experimental design of limited size.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 20 / **P2.1-811**

# Identification of Small Seismic Events Around Underground Nuclear Test Site in the Democratic People's Republic of Korea

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Recently, the detection of two small seismic events that have occurred close to sites where North Korea carried out underground nuclear weapons tests was reported in the literature. A seismic event, considered to be a small earthquake of magnitude 1.5, occurred on 12 May 2010 close to the site of the 25 May 2009 underground nuclear test (UNT) in North Korea. Another seismic event of magnitude 2.1 occurred on 11 September 2016, correlated to the 9 September 2016 UNT, and was reported as an aftershock of the UNT. We examine additional possible small seismic events around the North Korean test site using seismic data from stations in southern Korea and northeastern China, including IMS seismic arrays, GSN stations and regional network stations. We assess the best method to classify small explosions from earthquakes in the region based on time, location, source depth and spectral amplitude ratios of regional P and S waves from those seismic events. We will discuss issues raised by the capability of various seismic monitoring networks to detect such tiny explosions and earthquakes, and the best discriminant to classify various source types in the region.

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**P2.1 Characterization of Treaty-Relevant Events** - Board: 5 / **P2.1-836**

## Machine-Learning Event Classification in North-East China Using Augmented Data

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A transfer learning approach was adopted, using a VGG16 neural network model to classify earthquakes from non-earthquake events in North-East China, close to the North Korean test site. Magnitudes below 4 are considered for classification of tectonic events (earthquakes) from explosions. Because of the scarcity of observed explosion data, synthetic seismograms were generated using SW4 to augment the observed data so that overfitting doesn't happen during validation. Our preliminary experiment shows promising results which may help us identify any potential future small event.

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**Online e-Poster Session 1** - Board: 0 / **P2.1-861**

## Infrasound Signal Classification Method Based on Time-Frequency Graphs and Convolutional Neural Network

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The classification of infrasound signals has important application value in the fields of nuclear test monitoring, earthquake and other natural disaster warning. However, traditional infrasound signals classification methods are difficult to effectively extract the significant features that quantify event differences. To address this issue, this paper proposes an end-to-end infrasound signal classification method based on time-frequency graphs (TFGs) and convolutional neural network (CNN). Firstly, common time-frequency analysis methods, including short-time Fourier transform (STFT), wavelet transform (WT) and Hilbert-Huang transform (HHT), are used to convert six types of original infrasonic signals such as nuclear tests, chemical explosions and volcanic eruptions into TFGs. Then, a CNN model with multi-scale convolution layers was designed to automatically learn and extract the features of TFGs, achieving classification of infrasound signals. Finally, three TFGs were used as the input of CNN model for training and testing. The experimental results show that the classification accuracy of the three TFGs as model inputs exceeds 90%, with the STFT TFGs having the highest classification accuracy of 96.71%. In the case of small datasets and unbalanced number of samples, this model significantly simplifies traditional feature extraction process by integrating feature learning with signal classification and achieved better classification results.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 1 / **P2.2-062**

## Seismic tracking of space debris re-entries

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Uncontrolled space debris re-entries are a growing international concern, posing an increasingly greater risk on the ground as Earth orbit grows more crowded. Characterising the passage of these objects through the atmosphere is key to understanding the risks they pose, especially in evaluating whether any debris may have reached the ground. Using an example of a spent orbital module re-entering over California in 2024, we show that existing seismic networks are able to track the object's acoustic emission and hence constrain its trajectory, speed, and source dimensions and properties. This work demonstrates the potential use of seismology as a tool to track and characterise re-entering space debris, complementing measurements made from radar and optical stations. Further work will explore using IMS stations in debris trajectory inversions, potentially involving both seismic and infrasound data.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 2 / **P2.2-086**

## Presence of an acoustic signal on seismograms after a man-made event

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Sometimes, powerful quarry explosions can generate an acoustic infrasonic signal, and this can be recorded on seismic sensors. The appearance of an acoustic wave can be seen on seismograms, which are calculated based on the speed of arrival of the wave. If the azimuth coincides with the azimuth of the explosion, and the speed is V=0.33 km/sec, then we can confidently say that this signal was generated by an explosion. In this case, estimates of the speed of travel of the acoustic signal, determined by the time of the event and the distance, turn out to be slightly lower than V = 0.33 km/sec to V = 0.27 km/sec. If after a seismic event we observe an acoustic signal, this clearly tells us that the event is an explosion.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 3 / **P2.2-150**

## Neutralization of a WWII Aerial Bomb in the Port of Rijeka: Seismological Data Analysis

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During infrastructure works in the port of Rijeka, an unexploded WWII aerial bomb was discovered at a depth of 19 meters. The bomb measured 298 cm in length, 70 cm in diameter, and weighed 986 kg, including 690 kg of explosives. Due to its size and the proximity of residential and infrastructure facilities, it was deemed unsafe to neutralize the bomb at its discovery site through a controlled explosion. To ensure safety, residents were evacuated from the city center near the port before the operation. The neutralization took place on March 19, 2023, at 1:15 p.m. (UTC+1) at a secure location, where the shortest distance from the mainland was 8,300 metres. Seismological data collected from nearby stations played a critical role in the operation. This data allowed precise determination of the explosion's location and the energy released, confirming the success of the neutralization process while minimizing risks to nearby areas.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 4 / **P2.2-196**

## Seismic diagnostics and analysis of the consequences of a chemical explosion in an urban environment

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This paper presents the results of seismic data analysis related to a chemical explosion that occurred at a warehouse in Tashkent city (data 27.09.2023 UTC:21-52 ). The explosion caused significant destruction and was accompanied by the release of shock and seismic waves, which were recorded by seismological stations in the region.

The study includes an assessment of the explosion parameters, such as energy, intensity and propagation pattern of seismic waves. Based on seismological observations, the explosion power and seismic impact radius were determined. A modeling of shock wave propagation in urban areas was also conducted, which made it possible to assess the impact of the incident on infrastructure and the environment.

The results obtained indicate a high level of man-made hazard from chemical warehouses in densely populated areas and emphasize the need to strengthen monitoring, prevention and rapid response to such emergencies.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 5 / **P2.2-197**

## A Case Study with a Mobile Seismo-Acoustic Array, RAPAR

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A mobile seismo-acoustic array, RAPAR (RAsPberry ARray) was constructed with six Raspberry Shake-Booms, which are relatively small and cheap equipment. RAPAR is a stand-alone equipment with geophone, acoustic sensor, digitizer, solar power supply and LTE communication system but without a wind noise reduction system. RAPAR was deployed six months in a small peninsula, Homigot, located in the southeastern part of Korea and recorded clear seismo-acoustic signals from explosions at a mine at local distance range less than 10 km. A grid search with the first arrivals of seismic signals recorded at RAPAR was utilized for the localization of the events. The locations of the events were clustered within a small area of 255 m x 225 m. A waveform cross-correlation technique classified the events into five groups based on the seismic waveform coherence. The recorded waveforms at each group revealed the source characteristics of explosions at the mine.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 6 / **P2.2-332**

## Assessing Romanian infrasound stations performance for tracking repetitive explosive sources generated by military activity at near-regional ranges using IDC bulletins

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Infrasound data recorded with Romanian stations BURARI and IPLOR are processed and analyzed on routinely basis at NIEP by using capabilities of NDC-in-a-Box, i.e., DTK-PMCC, DTK-GPMCC and DTK-DIVA software.
This study focuses on the numerous and repeated high frequency signals (above 1 Hz) detected mainly from consistent sources related to the intense military activity caused by bombardment and shelling during Ukraine war. We used LEB events reported by IDC/CTBTO to search associated infrasound detections of the Romanian arrays. The observed and expected values of both backazimuths and arrival times for arrays recordings and LEB events were compared. Expected arrival time was estimated by using an average speed of 0.3 km/s of the sound wave to propagate to arrays straight from the event location. Allowed deviations between observed and expected values were considered as ±10 deg for backazimuth and ±10 min for arrival time. Deviating effects of zonal cross winds along the propagation path through the atmosphere is not considered for the observed backazimuths.
Approx. 35% of LEBs could be associated to infrasound detections. Almost 90% of these events are observed into a backazimuth interval between 10 and 120 degrees. Several examples of recurrent coherent infrasonic sources are showed.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 7 / **P2.2-337**

## Infrasonic and seismic source characterisation of an unknown sonic boom in the Tyrrhenian Sea

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On 20 June 2024, a powerful sonic boom shook the inhabitants of Elba Island (Tuscany, Italy) and was heard in a huge area on the Tuscan coast. The unknown phenomenon generated infrasonic and seismic signals which were recorded by three infrasonic arrays deployed in Elba Island (ELB), on Mount Amiata (AMT, southern Tuscany) and in Aosta Valley, and by 20 seismic stations located throughout Tuscany.
Array processing of infrasound data recorded at ELB and AMT arrays allowed us to locate the source in the Tyrrhenian Sea, ~50 km south of Montecristo Island. With infrasound ray-tracing we reconstructed a source altitude around 70 km in the atmosphere, consistently with signal arrival times at the two arrays.
The obtained localization is in perfect agreement with the source location (~50 km south of Montecristo Island and ~75 km altitude) computed analysing the arrival times at the 20 seismic stations and assuming a constant wave propagation velocity.
An estimation of the source yield ~1 kt is also given based on recorded infrasound.
The recorded waveforms, the estimated energy, as well as the reconstructed high source altitude are consistent with an unreported fireball event crossing the Tyrrhenian Sea and exploding in the high atmosphere.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 8 / **P2.2-338**

# Earthquake early-warning alert in Israel due to a 370 T explosion in southern Lebanon, October 26th, 2024

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On 26 October 2024, the Israeli Defence Forces (IDF) announced they triggered an explosion of 370 T in an underground Hezbollah facility in southern Lebanon, ~1 km off the Israeli border, generating a seismic moment equivalent to a M3.6 earthquake. Four seconds after detonation, the Geological Survey of Israel's (GSI) Earthquake Early-Warning System, *Truaa*, identified the explosion as a M5.2 event, mislocating the epicentre by ~25 km. Since this exceeded *Truaa*'s warning threshold (M4.5), an alert was automatically sent by IDF's systems up to an epicentral distance of 94 km. Seven seconds after detonation, the location and magnitude estimates were updated and stabilized to the actual location, and below the warning threshold.
The *Truaa* system operated as designed and the magnitude overestimation resulted from an unusually large explosion, short epicentral distances, and to mislocation due to a depth fixed at 8 km.
Real-time discrimination between earthquakes and explosions is still considered a research challenge that is pursued by our research team. Similarly, the Truaa algorithm, EPIC, cannot make such discrimination. Therefore, we examined and tested several manual procedures, to prevent the alerting of such scheduled explosions. Some of these are now part of GSI's procedures.
Consequently, the operational configuration of *Truaa* was not modified.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 9 / **P2.2-350**

# Delineation of Nuclear test event from Earthquake based on teleseismic data of PS26 station

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The PS26 station was established in Niger in 2005 on a granite batholith. The PS26 data is of unrivaled quality and contributes to strengthening the verification system within the IMS. The station remains in no capable mission, but there is hope to see this station getting back within the network. In this work, we will use data from the PS26 station in order to show its contribution by integrating also those from other stations to carry out a comparative study of the difference in the detection of a nuclear test compared to a natural phenomenon. On the basis of the ratio of P/S waves for each event, we will demonstrate, depending on the nature of the event, this approach which will be able to initially make a delineation between an event resulting from an explosion or that resulting from an earthquake.
Data related to a nuclear test from North Korea's nuclear test on September 3, 2017, where selected and from the wave morphology analysis, will show a difference from earthquake, which helps to confirm the high probability of nuclear test based on seismic data recorded.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 10 / **P2.2-351**

# Detection of an explosion at the Kakhovka HPP dam by the Ukrainian geophysical network

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Verification of events is a very important task for national monitoring systems. The Ukrainian NDC demonstrates this ability at least at the regional level. As an example, consider the event at the Kakhovka HPP dam that occurred on May 5, 2023. The estimated time in the source is 23:34:50 UTC. Determining the exact time of the event was accompanied by certain difficulties. First, its low energy and, as a result, a small number of seismic stations that recorded it. The signal was recorded by the Ukrainian seismic stations AKASG (PS45) and LUBAR. BURARI (Romania) and SORM (Moldova) stations also participated in the calculations. Second, mixing signals from different events in the same time interval. The spectrum of seismic signals indicated the explosive nature of the event. This was also confirmed by signals recorded by the Ukrainian infrasound network. The signals were recorded at the KPDA (Kamianets-Podilskyi), MAAG (Malyn) and GRDI (Horodok) infrasound arrays. The joint processing of seismic and infrasound data made it possible to localize and identify the event, as well as determine its energy parameters. The information obtained was included in the investigation materials, which confirms its objectivity and extreme importance.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 11 / **P2.2-352**

# A Seiscomp pipeline for seismo-acoustic events

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The department of Seismology and Acoustics (RDSA) at the Royal Netherlands Meteorological Institute (KNMI) monitors seismic and acoustic activity in the Netherlands with a dense network of seismometers and infrasound sensors. An important motivation for measuring infrasound in the Netherlands is to discriminate between vibrations originating from the solid earth, e.g. earthquakes, and from the atmosphere, e.g. sonic booms and explosions. This information is used to inform the general public. KNMI's infrasound network consist of multiple array stations of various apertures. The waveform data of these stations are freely available, both through FDSN webservices and the

Seedlink protocol. The arrays allow to (1) discriminate between coherent sound and incoherent noise and (2) determine the angle-of-incidence of the coherent sound waves. Localisation of acoustic events is possible by combing time-of-detection and the angle-of-incidence. In this presentation we present a recent development to develop an acoustic pipeline in Seiscomp for the automatic processing and localisation of acoustic events. The acoustic pipeline is running in parallel to existing seismic pipelines in AWS. We discuss the design of the pipeline, which consists of multiple Seiscomp modules, including automatic array processing. We present our first experiences with the pipeline and real-data examples.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 12 / **P2.2-389**

## Yield and Depth of an Explosion Inverted from Regional Seismograms with Source Complexity – Illustration of the Effectiveness Using Synthetic Seismograms

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A method to estimate yield and depth of explosions when accompanied by both DC and strong CLVD contributions will be presented. This paper will point out an amplitude deficiency in the CLVD green functions (GFs) constructed using no-torque three-orthogonal force dipoles (FDP). Vertically symmetric CLVD GFs are smaller by a factor of 2 than the DC source ZDD/RDD GFs, which is not accounted in the routine waveform inversion. Explicit radiation coefficients of the FDP vs. DC sources show this discrepancy (Saikia et al., 2008) which is also observed in the numerical SW4 vs. F-K seismograms. For source functions we used the time-domain source functions for explosions and delta function for the others. We set up the partials of the simulated explosion seismograms with respect to yield and depth, including the GF partials at each depth. We modified the TDSFs (Saikia, 2017, https://doi.org/10.1093/gji/ggx072) and the F-K code (FK_PROG, Saikia and Burdick, 1991, https://doi.org/10.1029/91JB00921) to code these analytic expressions for the GFs partials only at the source layer. We validated the new partials of explosion sources as independent of the elastic radius of the explosion sources using analytical and numerical results. In this study, we present the effectiveness of the method.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 13 / **P2.2-475**

## Seismoacoustic Simulations & Predictions of the Source Physics Experiments SPE Phase III (RVDC): Impact on explosion monitoring & discrimination

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The Source Physics Experiments (SPE) are a series of controlled chemical explosions at the Nevada National Security Site to gather observations to verify and validate explosions' physics-based numerical models and understand the genesis of shear waves to improve nuclear discrimination and monitoring capabilities. Executed between 2011 and 2016, Phase I encompassed six collocated chemical explosions executed in the hard granite with different yields at different depths. Phase II included four chemical explosions and was executed in 2018 & 2019 in soft dry alluvium geology. Phase III includes two chemical explosions in a dolomite geology and co-located with a 1997 earthquake. LLNL has developed a numerical framework to simulate from source-to-receivers the waves generated from the non-linear explosion source-region to linear-elastic distances. We will present SPE Phases I & II observed data with comparison to predictions and emphasize the main mechanisms of generating shear motions in granite and alluvium. For SPE III we expanded the capability to include fault activation and more non-linear source mechanisms to be able to predict the radiation patterns of the near field. Moreover, we developed schemes of uncertainty propagation of the geological characterization and geophysical parameters. We present impacts of those uncertainties on enhancing source discrimination.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 14 / **P2.2-580**

## Probabilistic Source-Type Analysis for Seismic Event Classification

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Moment tensors encode seismic source mechanisms and magnitudes, providing a basis for classifying seismic events. The moment tensor is a 3×3 symmetric matrix representing three orthogonal dipoles, with their magnitudes and orientations defining the mechanism. Decomposing the tensor into eigenvalues and a rotation matrix enables analysis and classification of source mechanisms on the lune source-type diagram, where positive isotropic sources (+ISO, explosions), negative isotropic sources (-ISO, collapses) and double-couple sources (DC, earthquakes) map to distinct regions. Traditional single-point classifications do not account for uncertainties spanning source types. To address this, we describe a probabilistic framework using probability density functions (PDFs) on the lune. We propose two approaches: (1) sampling posterior PDFs to compute conditional probabilities for source types (e.g., P(+ISO), P(-ISO), P(DC)) and (2) modeling the PDF as a mixture of elementary probabilistic source models. We demonstrate the framework by applying it to seismic events with diverse mechanisms, including earthquakes, collapses and the North Korean nuclear tests.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 15 / **P2.2-617**

# Source location of oceanic transform fault earthquakes constrained by IMS hydrophone triplets in the Indian Ocean

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T-waves are hydroacoustic waves that propagate as guided waves over long distances through the ocean, representing energy trapped in the Sounding Fixing and Ranging (SOFAR) channel. T-waves resulting from earthquakes have complex waveforms and simulations suggest that their long wave-trains are generated by scattering of upward traveling seismic energy at a rough seafloor and multiple reverberations in the water column. The aim of our study is to reveal whether T-phase locations represent earthquake epicenters.

We study submarine earthquakes in the Indian Ocean using the IMS Cape Leeuwin and Diego Garcia hydrophone triplets, applying a plane-wave array technique to obtain the back-azimuth and source location. For earthquakes at transform faults, we found that hydroacoustic source locations occur over the prominent valley of transform faults and not over the adjacent flanking shoulders. We infer that seismic energy generated by the earthquake is coupled into the ocean at the valley floor and not at the much shallower flanking mountains. Thereafter, converted energy is trapped in the transform valley, causing multiple water column reverberations, and subsequently energy leaking into the SOFAR channel. The hydroacoustic source locations agree well with epicenters derived from seismic waves and our understanding of seismic faulting at oceanic transform faults.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 16 / **P2.2-620**

# Revisiting the DPRK nuclear tests

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Since 2006, the Democratic People's Republic of Korea (DPRK) has conducted a series of six nuclear tests in the region of Punggye-ri, the latter claimed as a hydrogen bomb test, which occurred in September 2017. The estimated yield of these events ranged from 1 to 300 kilotons, based on various analyses, including seismic data and satellite imagery. The latest test was the most powerful, followed by increased seismic activity.
At Romania National Data Centre (NDC), as an essential aspect of seismic monitoring, we aim to discriminate tectonic events from nuclear tests. The analysis of the surface-wave magnitude (Ms) and body-wave magnitude (mb) and their relationship provides insight into the nature of the seismic event.
In this study, we apply the mb/Ms method, waveform analysis and spectral analysis to discriminate between tectonic events and underground nuclear explosions observed in the DPRK region.
To provide a more comprehensive verification framework, we used NDC-in-a-Box package capabilities for datasets available at the National Institute for Earth Physics (NIEP), International Monitoring System (MS) and European-Mediterranean Seismological Centre (CSEM-EMSC).

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 17 / **P2.2-624**

## Colossal seismic activity of the Fentale-Dofen magmatic segment in the main Ethiopian rift from September 2024 to date: potential source for ground truth events

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We are hosting a colossal seismic activity of the Fentale-Dofen magmatic segment to date in the main Ethiopian rift starting from September 2024. This earthquake swarm is caused by a dike intrusion beneath Fentale volcano and laterally migrating north toward Dofen volcano with a total lengt of over 40 km shown by both seismicity and InSAR data. Thousands of earthquakes with maximum magnitude of 5.8 Mw recorded the events felt in many towns in Ethiopia including the capital, Addis Ababa. Moderate damage is sustained around the epicenter area and over 40,000 people are displaced from their homes. As earthquake rupture was never felt before with such intensity and distance to many towns and the capital Addis Ababa, panic is high and this phenomenon is the talk of the town. The Fentale seismic and magmatic activity provide strong evidence for the Ethiopian local and federal governments and the public at large in the Metahara area which hosts the major trade route to the Djibouti port. Such intensive seismic activity in a well known place can be used as ground truth (GT5) events for estimating average travel time curve through the RSTT (Regional Seismic Travel Time) algorithms.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 18 / **P2.2-671**

## Mysterious Seismoacoustic Signals of Eastern Helwan Quarry Blasts, 2022

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Mysterious seismoacoustic events were reported at the beginning of 2022 near Helwan city. The majority of these events were recorded in our Egyptian National Seismic Network (ENSN). The source characteristics of these events were unknown. In May 2022, a temporary infrasound array station was established with a small aperture of 450 meters in Helwan. Throughout the six-month monitoring period, we employed a recursive Short-Term Average/Long Term Average (STA/LTA) trigger method across all sensors, leading to the detection of the impulsive seismoacoustic events. The infrasound propagation models, coupled with F-K analysis, further confirmed the locations and directions of the recorded events, providing robust evidence which could be correlated with the Planet satellite images of the referred detected azimuth directions from the infrasound array analyses.
Our study demonstrates the effectiveness of integrating seismic sensors with infrasound arrays for enhanced source characterization. The combination of these tools enabled precise discrimination of quarry blasts in Eastern Helwan. Additionally, our findings suggest that inexpensive sensors can be a cost-effective solution for monitoring higher-frequency events.
In conclusion, after investigating various seismoacoustic techniques, the mysterious signals were identified as originating from a significant construction project in Egypt: the high-speed railway train corridor.

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**P2.2 Seismoacoustic Sources in Theory and Practice** - Board: 19 / **P2.2-706**

# Source Identification and Discrimination Using Nearby Infrasonic and Seismic Sensors

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An experimental infrasound array, combined with collocated seismic sensors, detected in Southern Brazil an event characterized by waves arriving simultaneously at both types of sensors. This suggests a common source for the waves, traveling at the same velocity. However, different source types could satisfy these conditions. This study analyzes signals recorded by a four-element infrasound array, three triaxial seismic broadband stations, five uniaxial seismic sensors and five infrasound sensors. The goal is to identify the most plausible source responsible for generating these signals based on factors such as event location, wave velocity, frequency content, energy and ground vibrations. By examining the characteristics of the detected signals, the analysis identified an acoustic event, primarily based on wavefront velocity measurements. The acoustic waves were located far enough to be perceptible to local inhabitants. This raises several questions: What type of event could generate these signals? How could the local population perceive the event if no seismic signals were detected? If ground vibrations were felt, it would indicate a seismic event, which was not the case here. In this work, we present and discuss a methodology for event localization, interpretation and source identification, providing insights into the nature of the detected signals.

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**Online e-Poster Session 1** - Board: 0 / **P2.2-729**

## Distinguishing Earthquakes from Anthropogenic Events in Madagascar

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The earthquake catalog is a crucial component in seismic hazard assessment. However, it can be affected by non-natural earthquake sources. Hence, this study aims to differentiate between natural and non-natural earthquakes through machine learning techniques. We propose a convolutional neural network based on spectrograms for waveform classification, applied to the contexte of Madagascar. Our approach consists of three main steps:(1) generating the time-frequency representation of ground motion (spectrogram), (2) training and validating the model, and (3) testing and making predictions. We use a standard loss function and accuracy measure to evaluate the predictions. Our analysis is conducted in two steps. First, we adopt a supervised approach for 6051 known events in the central part of Madagascar. Then, we use the training outcome and perform prediction for non-categorized events. The results demonstrate that our model effectively distinguishes earthquakes from mining-related events. In the supervised learning phase, 97.48% were correctly labeled, while 2.52% received incorrect labels. These pre-trained data are subsequently used to predict unlabeled events. Our findings indicate that the model successfully learns the distinguishing features of the different classes, even for data coming from different parts of Madagascar. To further evaluate our methodology, we also compared the results with other deep learning techniques.

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**Online e-Poster Session 2** - Board: 0 / **P2.3-002**

## Air activity concentration of naturally occurring radioactive material (NORM) in the environment of the Nuclear Power Research Organization, National Research and Innovation Agency, South Jakarta, Indonesia, in 2023

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This study aims to identify the variety of NORM (Naturally Occurring Radioactive Material) radionuclides in the Nuclear Energy Research Organization, National Research and Innovation Agency, Pasar Jumat, South Jakarta, Indonesia, along with the concentration levels received by workers and to see the influence of radionuclides from countries outside Indonesia during 2023. Air sampling using the High Volume Air Sampler (HVAS) and Snow White tools. The results of NORM measurements in the air were analyzed by gamma spectrometry using a HPGe detector. The highest concentration detected by the snow white tool was K-40 with an average concentration of around

$8.19\times10^{-4} \pm 2.65\times10^{-5}$ Bq/m³, followed by Th-232 with a concentration of around $1.29\times10^{-5} \pm 3.67\times10^{-6}$ Bq/m³, Th-228 Around $8.78\times10^{-6} \pm 1.23\times10^{-6}$ Bq/m³, and Ra-226 As the lowest around $7.75\times10^{-6} \pm 6.43\times10^{-7}$ Bq/m³. The results of NORM radionuclide concentrations from air monitoring with the HVAS tool are lower than those from the Snow White tool. The concentration results are still below the threshold value of the activity concentration set by BAPETEN (Nuclear Energy Regulatory Agency) regarding the radiation safety of NORM storage, namely Ra-226 around 0.05 Bq/m3, Th-228 around 0.003 Bq/m3, Th-232 around 0.006 Bq/m3, and K-40 around 3 Bq/m3.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 1 / **P2.3-021**

# The benchmarking NORM map of Oman

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The ability to detect and localize radiation sources and special nuclear materials is key for many fields including nuclear security, safeguarding and nuclear materials nonproliferation. A fundamental aspect in in-field detection or imaging is the availability of an accurate natural background radiation map in the area of interest. In general, countries map background radiation levels for many reasons. First and considering the prior reasoning, benchmarking radiation levels is crucial for safety and security where any elevation in background levels directly indicates the necessity of action. Countries also map background radiation to study natural radioactive materials (NORM) and assess environmental impacts of various activities. With the current fast base at which nuclear applications are growing, it becomes more necessary than ever to generate natural background radiation maps. This will greatly enhance countries' abilities to encounter illicit activities in this field. The research in here presents an in-depth investigation of background radiation levels across Oman and its shores. The study gained notional interest and was awarded the Strategic Research fund for environment in Oman. Currently, the research work is in its early stages and the work here will discuss the methodology and the expected outcomes of this multi-disciplinary project.

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**Online e-Poster Session 2** - Board: 0 / **P2.3-058**

# Nuclear research reactors as source of radioxenon from neutron activation of stable xenon?

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Some strong indications were identified to confirm nuclear research reactors (NRRs) as a possible source of radioxenon emission generated by neutron activation from stable xenon. This source type is of high relevance to nuclear explosion monitoring for two reasons. First, the isotopic activity ratios may be confused with nuclear explosion signals. Second, neutron activation generates other radioxenon isotopes which would interfere with spectral analysis of IMS samples. Whether neutron activation may be a significant source is still not generally accepted in the expert's community. All relevant data found in the literature are gathered in multi-isotope activity ratio plots and compared with their own simulations. The plots involve emission data of five NRRs (HFIR, Texas TRIGA, Vienna TRIGA, FRM II and HANARO), as well as a typical light water reactor operational cycle, nuclear explosion scenarios and screening lines as context information. A confusing mismatch between the measured data and the results of simulations is found and discussed. This study finds evidence for at least one reactor being a strong source of radioxenon from activation. The purpose of this presentation is to inspire further discussion of these discrepancies and to advance the common understanding of radioxenon emissions resulting from neutron activation.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 3 / **P2.3-065**

# Possible source location analysis of high 135Xe observations at IMS noble gas systems to test the hypothesis of light water reactors being the source

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Whenever 135Xe is observed, it must originate from a fresh release due to its short half-life (9.2 hours). An activity ratio of 135Xe to 133Xe above 5 is an indicator for a possible nuclear test release. Therefore, it is important to fully understand observation of very high activity ratios of 135Xe to 133Xe in atmospheric air and even 135Xe without simultaneous observation of 133Xe as they occasionally occur at a few IMS stations (AUX04, JPX38, SEX63, NOX49, USX75, USX77). However, the nuclear processes causing such observations remain unexplained. One hypothesis of a possible source is power ramping down and the restart of light-water reactors (LWRs). For the mentioned IMS stations, the field of regard in the past 24, 48 and 72 hours are studied to identify a possibly common source region. The time of possible releases is compared with begin and end of outages reported in the Power Reactor Information System. The hypothesis is tested whether LWRs can explain some or all occurrences of high 135Xe concentrations. This has significant bearing on event screening for nuclear explosion monitoring. Specifically, conclusions will be drawn on the application of the 135Xe to 133Xe screening threshold.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 4 / **P2.3-071**

# Atmospheric dispersion modelling for a hypothetical nuclear accident

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Zaporizhya Nuclear Power Plant is facing the risk of unexpected accidents. If it is damaged, lots of radioactive materials will be released into the air. The atmospheric dispersion model named LADAS (Lagrangian Atmospheric Dose Assessment System) was applied to evaluate the behaviour of radioactive material released into the air for the hypothetical nuclear accident at Zaporizhya. The global meteorological data used with the input produced by KMA (Korea Meteorological Administration), and the amount of Cs137 released to the air was considered with those of the Chernobyl accident. From the simulations, the radioactive plumes were transported to the area of European countries near Zaporizhya in an early phase of the accident and they moved to Asian areas by westerlies after one week of the accident. A radiological emergency preparedness system in Korea has been developed to predict the behaviour of radioactive material released into the environment and to estimate the dose assessment for humans. It can evaluate the dispersion patterns of radionuclides in the air and ocean, and the short term and long term radiological effects of a nuclear accident on humans. The system is now operating to evaluate the radiological effects of nuclear facility accidents around the world.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 5 / **P2.3-106**

# Modelling of dispersion of nuclear device explosion debris in the ocean

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We present ocean modelling work aimed at detecting the debris from nuclear detonations in the ocean. By following the dispersion of near-surface warm pools of radionuclides from specific starting positions, we assess their likely spreading rates and pathways for some months after the explosions, enabling on-site monitoring or sample collection to take place with the best chance of detection.

Joint work with the UK Ministry of Defence / Atomic Weapons Establishment would then enable the estimation of likely radionuclide concentrations and detectability timescales.

In the modelling program, tracers are inserted at specified locations into high-resolution (1/4° and 1/12°) simulations of the global ocean state over the last 50 years using the NEMO ocean model. Starting from the near-surface warm pools of contaminated water expected to be left behind after the explosions, we consider two cases: (i) that there is no interaction between the nuclear explosion and the sea floor and that the radionuclides all go into solution, so they are just advected and diffused without any settling, and (ii) the nuclear explosion interacts with the sea floor, and nuclear debris is adsorbed onto particulates raised from the seafloor that will gradually settle as they are advected and diffused.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 6 / **P2.3-139**

## Influence of routine discharges from nuclear power plants in the Florida peninsula on the radioxenon background in the northern Caribbean Sea

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Previous studies on the trajectories of air masses from nuclear power plants in the Florida peninsula showed that they contribute to the radioxenon background in the northern Caribbean Sea when the center of the migrating anticyclone was in the Gulf of Mexico and Lousiana, North America.

The objective of this work is to determine whether the Turkey Point and Saint Lucie NPP discharges transit the northern Caribbean Sea for different synoptic configurations of the migratory anticyclone when its center is in North America. Therefore, the trajectories were simulated with the HYSPLIT trajectory model at an altitude of 500 m.

The simulations revealed that the air masses transited the northern Caribbean Sea when the centre of the anticyclone was in the centre of North America and in the state of Texas. However, when the centre of the anticyclone was located southeast of the United States and northeast of the Great Lakes, the air masses deviated toward the Gulf of Mexico. The southeastern states analyzed were Alabama, South Carolina, Florida, Georgia and Tennessee. These results indicate that the contribution of discharges from both facilities to the radioxenon background depends on the location of the centre of the migrating anticyclone in North America.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 8 / **P2.3-195**

# Determination of turbulent diffusion coefficient using atmospheric radon concentration

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The turbulent diffusion coefficient is the rate at which turbulent motion disperses radionuclides. It controls the rate of spread of their concentrations into the atmosphere, thus influencing their behaviour. The turbulent diffusion coefficient is an essential parameter in the study of atmospheric transport, and the accurate determination of its value in the atmosphere is crucial. This study aims to develop a novel method for accurately determining the turbulent diffusion coefficient using atmospheric radon concentration. The Alpharad Plus radiometers were used to measure radon activity concentration simultaneously at two different heights. The turbulent diffusion coefficient was calculated using a formula dependent on activity concentration and height. The results showed that precipitation affects the radon activity concentration near the earth's surface. It also shows that radon activity concentration is inversely correlated with the turbulent diffusion coefficient in the atmosphere. The validation findings indicate that the turbulent diffusion coefficient in the atmosphere can be calculated using radon concentration. This method can be used in an atmospheric transport model to accurately study and predict the behavior of radionuclides in the atmosphere during a nuclear incident.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 9 / **P2.3-198**

# Rapid and versatile radionuclide source term estimation, including host rock seepage and atmospheric venting

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Atmospheric transport modelling requires the rapid estimation of a radionuclide source term (including radioxenon) potentially released to the atmosphere from an underground nuclear cavity. A versatile model must include venting to the atmosphere and seepage into the host rock, allowing for barometric pumping. The nuclear cavity is connected to the ground surface by two interacting media, namely a fracture network embedded in a porous matrix. The first one is schematized as one-dimensional, and the second as spherical. The carrying gas is compressible, but still isothermal. Convection is governed by Darcy scale equations in both media. The transport of radionuclides from the cavity is governed by a convection-diffusion equation in the fracture network, and by a diffusion equation in the porous matrix. These equations are discretized by the finite volume method with a time implicit formulation which yields tridiagonal systems to solve. Moreover, the convection-diffusion equation uses a flux limiting scheme. Non linearities mostly due to compressibility are addressed by classical Picard schemes. Examples are given to illustrate the precision and the efficiency compared with full three dimensional codes. This model is to be implemented in STM_toolkit, the source-term modeling software in use at the French NDC.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 10 / **P2.3-203**

## SATEx (Subsurface-Atmosphere Tracer Experiment): Ground truth for the atmospheric detectability of xenon emitted from an underground cavity

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The detection of underground nuclear explosions by means of the radioactive gases generated during the explosion requires a sufficient fraction of radionuclides to be emitted to the atmosphere. In the case of late seepage observed after a few days to a few weeks, this fraction is very small and results from the transport of gases under the combined effects of thermal gradient and barometric pumping. However, a model suggests that these diffuse emissions at the ground surface, integrated in space and time, could together constitute a source term sufficient to be detectable with current technology. The SATEx (Subsurface-Atmosphere Tracer Experiment) project proposes to verify this model by experimentally injecting stable xenon from an underground cavity and monitoring it in the geosphere and atmosphere at the small-scale instrumented site of the Roselend natural laboratory (France). Numerous infrastructures, devices and instruments allow measurements in rock, soil and atmosphere, including a xenon concentration enrichment device (based on silver-doped zeolite) coupled to a mass spectrometer. A transport model was calibrated on the basis of previous experiments and was used for the design of the experiment.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 11 / **P2.3-204**

## Coupling condensation with decay-chains: A refined model for the calculation of the radioxenon source term produced by underground nuclear explosions

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The relative abundances of radioxenon isotopes in underground nuclear explosions depend on the direct production by fission and the β-decay of their radioactive precursors. Since the precursors are moderately volatile elements that can condense into the magma within the nuclear cavity as the system cools off, the radioxenon budget available for subsequent migration to the atmosphere,

as well as its potentially distinctive isotopic signatures, are modified as the precursors are removed from the gas phase. We have developed a new model coupling condensation with radioactive decay to predict the behavior of radioxenon and its precursors during the time evolution following an underground nuclear explosion. For each nuclide from the relevant decay chains, thermodynamic calculations for a rock chemical composition depending on the underground conditions were used to estimate the vapor pressure, the net condensation rate and the speciation of each nuclide in the decay chains, along the time-evolving pressure-temperature conditions. This can be extended to any fission chain and gives a more reliable estimate of the source term for different explosion configurations.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 12 / **P2.3-213**

# Improving radioxenon background estimates based on nudging observations and machine learning

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Standard atmospheric transport modelling can be of great help for categorizing specific radioxenon observations but will not prevail on average when it comes to screening out nuclear explosion signals that are mixed into the global industrial background. The challenge pertains to both poorly characterized emissions and uncertainties in the modelled dispersion. Improved screening can be attained by applying the FLEXPART-LCM (Linear Chemistry Module). It employs a global domain populated with particles advected throughout the atmosphere. Particle masses can be adjusted using a nudging technique, which computes additional mass tendencies for particles within the observation kernel. We will investigate the following exploitation potentials enabled by FLEXPART-LCM: 1) In case of a significant waveform event nudging could be turned off to avoid assimilating any signals from a nuclear explosion. FLEXPART-LCM would then run freely for a few sampling times. Resulting modelled radioxenon background concentrations at IMS stations can still be expected to be more accurate and nuclear signals should become more evident. 2) A more sophisticated use of FLEXPART-LCM output would be to perform nudging without interruption in case of an event of concern. Rather than suspending the nudging, nudging increments could be continuously analyzed via machine learning to identify anomalies.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 18 / **P2.3-215**

# Creating time pattern models of radioxenon releases from nuclear facilities based on stack measurements

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Knowing the time pattern of radioxenon releases is crucial for expert analysis in nuclear explosion monitoring. The standard assumption, which uses a constant discharge rate based on the average of the annual total, is overly simplistic. The noble gas measurement systems are not typically sensitive to continuous emissions and instead usually observe puff emissions. The measurement data from the Source Term Analysis of Xenon (STAX) project is used to characterize typical release patterns at different time resolutions. These release variations over time are generalized for specific types of facilities, including medical isotope production facilities and nuclear power plants, based on the available release data. Key parameters include the frequency, shape, duration, amplitude of puffs, and the proportion of the total annual discharge that is released in the form of puffs for each radioxenon isotope individually. The results from using radioxenon release models created from STAX data for specific types of nuclear facilities will be presented by using examples to illustrate the enhancements in nuclear explosion monitoring achieved by employing time pattern models instead of relying on the continuous source assumption. Facility type-specific discharge patterns derived from STAX measurements are more powerful in radioxenon event analysis than a constant emission assumption.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 14 / **P2.3-218**

# Applications in nuclear explosion monitoring using predictive source models for radioxenon discharges from nuclear facilities

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Radionuclide monitoring for nuclear explosions requires sufficient information and an adequate understanding of existing radioxenon sources which are frequently observed as background in atmospheric noble gas samples. In the absence of measured discharge data from nuclear installations, one can only revert to rough approximations of discharges based on publicly available information. In many cases, only generic estimates of annual total releases are available, and typically, a continuous discharge of the average amount is assumed. Using release data collected by the Source Term Analysis of Xenon (STAX) project offers a solid basis for the creation of source models for medical isotope production facilities (MIPFs) and nuclear power plants (NPPs). This presentation provides example source models for three model categories which include: patterns, distributions, and discharge characterizing parameters. The source models' usefulness in nuclear explosion monitoring is demonstrated through specific applications of event screening and through the use of expert technical analysis methods to identify a release event time, location, source strength, and source type. Some of the models facilitate disentangling different sources that influence the same samples.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 16 / **P2.3-232**

## Series of Chemical Explosive Experiments with Subsurface Noble Gas Transport and Atmospheric Releases

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Understanding the propagation of the waveform and radionuclide signals is an important component of the International Monitoring System. On October 18th, 2023 we executed a 16.3 T chemical explosive experiment with stable radioxenon and tritium tracers to understand pressure-driven transport through the subsurface. The initial chemical explosion and subsequent gas migration were monitored with a network of seismic, infrasound, EM, radionuclide, and stable gas sensors. The waveform sensors provided characterization of the seismic, acoustic, and EM signals at varying distances immediately following the chemical explosion. The material sensors included real-time radioxenon, tritium, and high explosive by-product sensors, as well as a series of samples that collected gas and water for laboratory measurement. This experiment was followed by venting tunnel gases into the atmosphere for local transport and detection. A borehole drilled back into the cavity produced by the explosion is planned. Additionally, we have also implemented other stand-alone atmospheric release experiments. In this presentation, we outline the experimental conditions and highlight the primary detection mechanisms and results along with plans for future experiments and drilling back into the cavity. Subsequent presentations will cover specific aspects of the experiment such as tracer production/emplacement and measurements of the tracer gases.

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**Online e-Poster Session 2** - Board: 0 / **P2.3-259**

# Multiscale geocharacterization of volcanic tuffs in support of source discrimination modeling

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A series of multi-physics experiments, referred to as Physics Experiment 1 (PE1), is underway at Aqueduct Mesa within the United States' Nevada National Security Site (NNSS). The PE1 series includes detonation of underground chemical explosions that will provide key observations relevant to source discrimination models and algorithms. An important aspect in understanding the signals generated by these experiments is detailed characterization of the testbed geology. Here we present geologic, hydrologic, and geomechanical properties collected and analyzed from the bedded sequence of Miocene pyroclastic tuffs at Aqueduct Mesa. Analysis of geologic samples has allowed us to constrain important material properties, including seismic velocity, two-phase permeability, material strength properties, mineral and elemental composition, and water saturation. This suite of characterization data is synthesized with borehole log data for integration into the testbed's Geologic Framework Model, which directly feeds predictive models of seismic wave propagation, gas transport, and source mechanics.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 17 / **P2.3-279**

# Statistical analysis of nuclear power reactor outages as sources of elevated radioxenon releases

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Radioxenon discharges from nuclear power reactors (NPPs) are frequently detected by the noble gas monitoring systems of the International Monitoring System. However, the standard assumption of continuous releases is not realistic. It has been demonstrated that ramping power down and up during operations are occasions of elevated discharges, which are most likely to be observed. Despite this, only limited information is available about these relevant NPP operations.
This study utilizes comprehensive outage data from the International Atomic Energy Agency's Power Reactor Information System (PRIS) to statistically analyze the frequency and duration of outages. The analysis focuses on planned full outages, during which reactor units are disconnected from the grid for purposes such as inspection, maintenance, repair, refueling, or a combination of these activities. The statistics are presented by reactor type, including Boiling Water Reactors (BWRs), Gas-Cooled Reactors (GCRs), Pressurized Water Reactors (PWRs), Pressurized Heavy Water Reactors (PHWRs), and Light Water Graphite Reactors (LWGRs). The results of this study support event screening and expert technical analysis of radiological events of interest, helping to distinguish reactor emissions from nuclear explosion signals and enhancing the understanding of the operational sources of elevated radioxenon releases.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 13 / **P2.3-286**

## Nudging: Making Background Predictions with Atmospheric Transport Modelling Sensitive to IMS Observations

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Radioxenon emissions originating from a variety of nuclear facilities (e.g. nuclear power plants) induce a variable and observable background that poses a challenge for the global monitoring of nuclear explosions since it may conceal signals resulting from a nuclear test explosion. More precision is required to accurately model civilian facilities so that noble gas detections can be screened out as a civilian source. Improved screening can be attained by iteratively adjusting emission values of these sources in the atmospheric transport modelling (ATM) runs. For a regional domain and a timeframe of a few weeks, IMS observational data are compared with ATM estimations using annual release averages from regional nuclear power plants (NPPs). The activity concentrations at IMS stations are estimated by combining the activity (Becquerel) from the sources with the modelled source-receptor sensitivity between the IMS radionuclide stations (receptors) and the nuclear powerplants (sources) as a dilution from ATM. NPP releases, linked to those estimations, that deviate significantly from the detections are identified and are adjusted for an updated ATM estimation in all stations. This basic approach results in a better match between moderately known source releases and IMS observations while extrapolation to seasonal timeframes might be appropriate.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 19 / **P2.3-290**

## Source term analysis of 127Xe from surface and subsurface tracer transport experiments of the PE1 series

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The development and validation of noble gas transport models through field collected data is critical in the improvement of nuclear explosion monitoring techniques. Complex surface terrain in the area of release can drastically impact the transport of the resulting plume and the subsurface geology can alter material flow to the surface, resulting in large discrepancies in release times, complicating arrival times at International Monitoring System stations and subsequent atmospheric transport modeling analysis. To better understand these effects and provide validation data for modeling, 127Xe was utilized as a radiotracer in multiple large-scale, multi-physics field experiments of the Low Yield Nuclear Monitoring (LYNM) Physics Experiment 1 (PE1) series. Aliquots were collected from both a metrological surface release experiment (REACT) and a subsurface chemical explosive experiment (PE1-A). Release systems deployed in both experiments captured gas from the source container before experiment execution and were shipped to Pacific Northwest National Laboratory (PNNL) for post-analysis. Both surface and subsurface systems collected telemetry data related to pressures, temperatures, and flow rates of the radioxenon during release operations. Through a combination of telemetry data, laboratory spectroscopy of the aliquots, and xenon concentration measurements, the total inventory in both atmospheric and subsurface releases was calculated.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 20 / **P2.3-294**

## Source Term Analysis of Xenon (STAX): 7 Years of Hardware and Software Lessons-Learned

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The Source Term Analysis of Xenon (STAX) project is an international technical collaboration that has been installing stack monitors in partnering nuclear facilities and sharing stack effluent data with National Data Centers for use in better understanding Xe background sources detected by the International Monitoring System (IMS). The STAX project is now in its 7th year and during the course of the project has had many lessons learned about the setup and maintenance of the equipment, data acquisition, data transfer, and data analysis. The current project status will be presented along with the hardware and software lessons learned from over the last 7 years.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 21 / **P2.3-296**

## CARATk, a new toolkit for radionuclides atmospheric transport simulation for the CHIMERE model

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We present our work on the CHIMERE Assisting Radioactive Analysis Toolkit (CARATk), a new toolkit for the CHIMERE chemistry transport model. This toolkit will permit simulation of transport, chemistry and physical processes of radionuclides in the atmosphere.
Our poster will focus on two main points in our development of CARATk.
Firstly, we validate the eulerian transport CHIMERE by comparing CHIMERE performances to the Lagrangian model FLEXPART, frequently used in radioactive pollution modeling, in the context of the Ru-106 pollution detected in 2017 over the Northern Hemisphere.
Secondly, we will elaborate what is CARATk, what is its aim and what is it already capable of modeling. We will present uses of CHIMERE with CARATk in the context of the Fukushima accident to illustrate some of its capabilities, limitations and prospects for future developments. We simulated a purely theoretical emission of the first element of 99 radioactive decay chains and checked that all daughter nuclides were appearing correctly with 806 reactions. We also compared the results of a simulation using the real emission with data from IMS stations for Iodine-131 and Xe-133.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 22 / **P2.3-298**

# Transport variability of Xenon and Tritium following an Underground Explosively Driven Release

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The measurement of radionuclides is continually performed by International Monitoring System (IMS) operated by the Comprehensive Nuclear-Test-Ban Treaty Organization Preparatory Commission (CTBTO PrepCom). The detection of radionuclides plays an important role in confirming if an explosion is nuclear or chemical. As radioactive gases are transported through the subsurface environment, there is potential for fractionation between the species. The fractionation between species is important for understanding the source term for isotope detectors. During a recent field experiment, radioactive tracers were released along with a high explosive source. The experiment

was aimed at understanding the pressure driven transport of materials. Two tracers of interest for this study were 127Xe and tritium gas. The transport of these gases is expected to vary as a function of geologic media, gas sizes and gas chemistry. Real-time measurements were made for 127Xe in gas sampling boreholes and within the tunnel, while tritium real-time measurements were performed throughout the tunnel. In addition to the real-time measurements, grab sample measurements from select gas boreholes and tunnel locations were performed on 126Xe, tritium gas and HTO. In this presentation, we compare the transport of xenon with tritium through a series of measurements from both real-time field and laboratory systems.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 23 / **P2.3-321**

## Improving Global Xe-133 Background Concentration Fields by Applying Nudging Techniques in FLEXPART-LCM

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Understanding and accurately modelling Xe-133 is fundamental for the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) to monitor compliance with the Comprehensive Nuclear-Test-Ban Treaty. Therefore, the potential of nudging techniques within FLEXPART-LCM, the Linear Chemistry Module of FLEXPART 11, to improve global Xe-133 background concentration fields is examined. Based on simulations and observations from 2014, the analysis provides a detailed assessment of this approach.

Nudging, which involves adjusting mass tendencies for particles near observation stations, enables simulations to align more closely with observations. Its application resulted in substantial overall improvements, including significant reductions in bias and mean square error, as well as higher coefficients of determination at most observation stations. However, improvements at independent validation stations excluded from the nudging process were relatively minor, likely due to the limited spatial coverage of the observation network and the short atmospheric lifetime of Xe-133.

Expanding the observational network could further enhance the effectiveness of this approach, broadening its applicability to independent validation stations and improving the accuracy of global Xe-133 background concentration fields. Such advancements are critical for strengthening the International Monitoring System (IMS) of the CTBTO and advancing nuclear event verification efforts.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 24 / **P2.3-322**

# Temporal and Geographical Distribution of CTBT-Relevant Xenon Isotopes: Insights into Global Background Patterns

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The detection of xenon isotopes in the atmosphere plays a critical role in monitoring nuclear explosions under the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Understanding the temporal and geographical distribution of CTBT-relevant xenon isotopes, such as 131mXe, 133Xe, 133mXe, and 135Xe is essential for distinguishing between natural, medical, and anthropogenic sources and potential nuclear tests. This study provides a comprehensive analysis of global background levels of these isotopes, integrating data from atmospheric monitoring stations, and meteorological data. Key findings reveal significant variability in xenon isotope concentrations. Temporal fluctuations, including seasonal and diurnal cycles, are analyzed to better understand their correlation with atmospheric transport dynamics. The results contribute to refining the detection thresholds and improving discrimination methods for treaty verification purposes.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 25 / **P2.3-346**

# The Importance of Background Analysis of Xenon in Nigeria: A Study Within 4°–14° N Latitude and 3°–14° E Longitude

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A background analysis of xenon in Nigeria would enhance the understanding of its release and dispersion from reactors and natural sources. Although Nigeria lacks a nuclear power plant, it operates a research reactor in Zaria (11.1512° N, 7.6546° E) and is planning a 2GW multipurpose research reactor in Sheda (8.8569° N, 7.0434° E). Nigeria's strategic location between IMS stations in Niger (RN48) and Cameroon (RN13 and PS26) offers a unique opportunity for xenon background studies within a semi-dense network. The establishment of the West Africa Nuclear and Radiation Monitoring, Detection, and Response Centre will further enhance radiation monitoring, contribute data to the IAEA's IRMIS, and potentially link to the CTBTO IDC. Conducting xenon background analysis in Nigeria would significantly contribute to global radionuclide studies, while also providing essential knowledge for the accurate understanding and categorization of radioxenon detections.

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**Online e-Poster Session 2** - Board: 0 / **P2.3-409**

# Radionuclide background within the African continent as monitored by the CTBTO – IMS Radionuclide network

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Effective emergency preparedness in nuclear accidents requires understanding the observed radionuclide background, which the African continent is rarely studied for this purpose. This has made it necessary to evaluate the regional radiological baseline data that could be used for radiation impact assessment. The study fills this gap by cataloguing and monitoring radionuclides as detected by the Comprehensive Nuclear-Test-Ban Treaty Organization's (CTBTO's) International Monitoring Systems (IMS) from certified and operational particulate radionuclide stations MRP 43, CMP 13 and TZP 64 within the African continent. This report analysed data from the first quarter of 2011. MRP 43 recorded typical background radiation until days 85 to 108 when multiple anomalous anthropogenic radioactive isotopes of iodine (I-131, I-132), caesium (CS-137, CS-136, CS-134), tellurium (TE-129, TE-129M, TE-132) and lanthanum (LA-140) were detected. CMP 13 recorded anomalous anthropogenic radioactive iodine (I-131) and caesium (Cs-134, Cs-137) between days 91 and 107. However, typical background radiation was detected at TZP 64. The activity concentrations of the fission product at MRP 43 were more than 10% higher than that detected at CMP 13. The study gives insight into the dynamics of the background radiation within the African continent.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 26 / **P2.3-416**

# Comparison of Xe-133 activity concentration background in the Northern and Southern Hemispheres

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This study is about radioxenon Xe-133 background in the Southern and Northern hemispheres and to discuss the influence of this context on nuclear test identification.
The study was carried out in four CTBTO stations in Northern and Southern hemispheres. They were chosen taking into account NPPs and medical facilities close the stations. Data was extracted from Review Radionuclide Report (RRR) through RN Toolkit in a period of ten years, from 2014 to 2024.
Data of different stations was separated by seasons and split depending on the level of activity concentration of Xe-133, as well as was differentiated for both hemispheres. Results show that the Xe-133 activity concentration in the Southern Hemisphere is lower than in the Northern one. After Covid-19 pandemic the background of Xe-133 in the Southern Hemisphere raised due to the increase

of radiopharmaceuticals production. The Northern Hemisphere exhibits a complex radioxenon environment due to the proximity of nuclear power plant reactors and research reactors.
Climatic and environmental differences between both hemispheres and also NPP define the radioxenon background.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 27 / **P2.3-417**

## Estimation of Xe133 release from activity concentration measurements with background signal

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Estimation of Xe133 emissions associated with nuclear tests is a challenging task for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) due to noble gas background emissions from nuclear power plants, research reactors, and medical isotope production facilities. These background emissions make data interpretation from the International Monitoring System (IMS) a complex issue since the standard linear inverse model for Xe133 measurements often introduces significant errors. We investigate methods to separate the background signal from potential nuclear test signal, enabling estimation of the Xe133 source term. Our most advanced model seeks for separation of the mixture of signals from civilian and nuclear sources, estimating the Xe133 source term from the rest of the signal after subtraction of the civilian signal.
The methods are evaluated using data from the 1st Nuclear Explosion Signal Screening Open Inter-Comparison Exercise (NESSI) 2021. Results are compared against ground truth information on Xe133 source characteristics, leading to improvement of the identification of nuclear explosion signals in complex atmospheric backgrounds.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 28 / **P2.3-434**

## Enhancing Source Estimation in CTBTO Web-Grape

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The estimation of a source in the CTBT context is an ill-posed problem that is highly sensitive to small variations in data, whether meteorological information or radionuclide concentration values. The current version of the Web-Grape software includes three methods for identifying possible source regions. The first two methods rely on the correlation between measured concentration values and corresponding modeled values, employing two distinct correlation measures: Spearman and Pearson. The third method uses the number of source-receptor sensitivities (SRS) exceeding a threshold value as an indicator of potential source areas. Notably, while Spearman correlation is more robust than Pearson correlation, the robustness of both depends on the number of data points used for estimation. To address this, we propose a new statistical method that combines correlation and SRS counts to improve the accuracy of identifying possible source regions. The effectiveness of this method is demonstrated through synthetic and real-world case studies.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 29 / **P2.3-476**

## End-to-end numerical simulation of explosion cavity creation and circulation processes, subsurface gas venting & transport, and prompt atmospheric releases

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A numerical study of conjugate flow, heat and mass transfer by natural convection of noble gases within an underground cavity partially filled with molten rock is presented. The molten rock is initially considered at rest at an initial temperature and concentration. The molten rock is viscous and possesses strength that is temperature and crystal fraction dependent. Under natural conditions, convection cells are developed within the molten rock leading to circulation, mixing and degassing of the initially trapped gases. Furthermore, the molten rock as well as the degassing enhances the conjugate convection flow in the air gap within the cavity. We illustrate the onset of the different regimes and their combined effect of flow, heat and mass transport of different gas species, the fraction of molten rock and their impact on the noble gas fractionation. We also present a sensitivity analysis of the effect of the outer cavity boundary condition on the heat loss and cooling to the adjacent rock formation and its eventual release to the atmosphere. We demonstrate several scenarios of underground prompt releases to the atmosphere using a first-ever fully coupled prompt subsurface-to-atmospheric transport without ad-hoc boundary conditions between physics-based domains or handshakes between different numerical codes.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 30 / **P2.3-487**

# Results of the ongoing monitoring activities at the CTBTO station in Mauritania

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The RN43 station, located in Nouakchott, Mauritania, is a key component of the International Monitoring System (IMS) under the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). Established in 2006, the station plays a crucial role in detecting and analyzing airborne radionuclides, contributing to global atmospheric transport models and radiological risk assessments. Due to its semi-arid desert climate, proximity to the Atlantic Ocean and exposure to dominant northerly winds, RN43 provides a unique vantage point for tracing radionuclide dispersion patterns in an arid environment.

In July 2022, a supplementary PM10 measurement campaign was initiated at RN43 to investigate the relationship between airborne particulate matter and radionuclide concentrations, particularly in the context of sandstorms and seasonal meteorological variations. While this initiative enhances the station's analytical capacity, radionuclide surveillance remains the primary focus of RN43's mission.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 31 / **P2.3-515**

# Review of data from radionuclide monitoring (RN64) station from 1 January 2010 to 31 October 2024; Insights and Recommendations

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In September 2024, anthropogenic radionuclides observed from RN64 station located in Tanzania. This incident triggered us to make a review of data analyses from CDC from January 2010 up October 2024. Key finding includes the detection of both natural and anthropogenic radionuclides (fission and activation products). However, the interest was on anthropogenic radionuclides (fission and activation products) which are on the list of Comprehensive Nuclear-Test-Ban Treaty (CTBT) relevant radionuclides as an indicator of a potential nuclear test. Detected anthropogenic radionuclides were; Co-60, Cs-137, Cs-134, Na-24, I-133, Nd-147, Zn-65, Nb-95, Zr-95, Sn-113 and Co-58. Detected natural radionuclides were Be-7, K-40, U-235, and decay products of Th-232 and U-238. These results indicate that there have been instances of air pollution due to anthropogenic radionuclides released from atmospheric nuclear weapon tests or operating nuclear facilities, such as nuclear power plants. Recommendations include: perform comprehensive investigation on the source and cause of the unusual emissions, analysis of aerosol samples coupled with Atmospheric Transport and Dispersion Modelling (ATDM), perform simulation model by available computer code simulation tool and dispersion modeling to establish the extent of anthropogenic radionuclides spread in the country.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 32 / **P2.3-541**

## Attribution of the radioxenon release sources, detected by SAUNA III and three SAUNA QB networks in Lithuania

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Radiation Protection Centre has launched a network of three SAUNA QB and one SAUNA III atmospheric radioxenon measuring stations in Lithuania. Measurements are performed regularly since the end of 2024 and the number of episodes with the elevated radioxenon (mostly 133Xe) concentrations were detected. The backward atmospheric transport modeling using HYSPLIT computer code allowed us to identify the most probable radioxenon release source, attributable to each episode of contamination. The analysis revealed that in most of the cases detected radioxenon was transported from the neighboring Belarusian NPP. In some cases, the radioxenon atmospheric releases from the medical isotope production facilities in Belgium/Netherlands and Poland were registered. Also, sources of release from the NPP in the south of Sweden as well in Ukraine and Russia were identified. The usage of the non-stop radioxenon measurements data obtained in the network of 4 different stations in Lithuania allows us to trace the detected sources of release with improved certainty.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 33 / **P2.3-562**

## Relevance of high 135Xe/133Xe isotopic activity ratios at LWRs for nuclear explosion monitoring

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Isotopic activity ratios of 135Xe to 133Xe above 5 are considered as an indicator for a possible nuclear test release. High activity ratios of 135Xe to 133Xe in atmospheric air and even 135Xe without simultaneous observation of 133Xe are occasionally observed at IMS noble gas systems. Whenever 135Xe is observed, it must come from a fresh release because its half-life is just 9.2 hours. Despite all efforts, the sources of high 135Xe to 133Xe activity ratios are still not sufficiently well identified and may originate from different source types. This presentation begins with an overview of the 135Xe to 133Xe activity ratios and these isotopes' source strength as they are typically released by various nuclear installations. The most likely source of many high 135Xe observations are LWRs at

the time of power ramping up or ramping down. A nuclear reactor core simulation was undertaken to investigate the influence of downtime and other parameters on the 135Xe to 133Xe activity ratios. Conclusions are drawn on what specific scenario might cause the highest ratios and what source term could be expected.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 34 / **P2.3-585**

## Regional-Scale Air Pollution Source Identification Using Backward Particle Dynamics

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Air pollution, including radiological pollution, is one of the most harmful consequences of industrialization because of its strong influence on both human health quality and climate in general. Often a need appears to identify one single strong source of air pollution. Such a source may be the result of accident or routine release from nuclear industry. We propose a new algorithm for a single pollution source localization. The proposed algorithm uses the source-receptor matrix concept and assumption about the linearity of pollution transport that allows us to use the pollution spread simulations backward in time. In particular realization, we make use of the weather regional forecast model WRF for airflow simulation and of lagrangian particle dispersion simulation software FLEXPART-WRF for pollution advection simulation both forward and backward in time. As a result, our algorithm produces the semi-empirical heatmap of possible pollution source locations with marked point of the biggest probability and estimative emission intensity at this point as a function of time. The algorithm is tested on several synthetic and practical cases and compared with other solutions in this field. Results on the European Tracer Experiment data demonstrate competitiveness of the proposed approach and its applicability to radioactive pollution monitoring.

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## Updated status and analysis of ongoing temporary noble gas background measurement campaign in Japan

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In 2017, the Government of Japan has decided to make a voluntary contribution to further strengthen the capabilities of the CTBTO verification regime. As part of that initiative, two transportable noble gas measurement systems were deployed in Japan, in Horonobe and Mutsu. They started operations in January 2018 and March 2018, respectively. In January 2025, a third transportable measurement system was deployed in Fukuoka, Japan, completing a mini-network configuration (including the IMS system JPX38) across the country. This setup will enable observations of relevant detections using multiple measurement systems located approximately 500 km apart. Continued operation of these systems is supported financially through voluntary contributions from both the European Union and Japan.

To date, several hundred samples have been collected and measured by the three systems. Measurement spectra are automatically transmitted to the IDC, where they are processed in a non-operational database. These spectra are routinely reviewed, with particular emphasis on the four radioxenon isotopes of interest for CTBTO monitoring (131mXe, 133mXe, 133Xe and 135Xe). Both the analysis results and raw data are made available to State Signatories through the Secure Web Portal.

This presentation provides an updated overview of the measurement campaign, along with preliminary analysis results of observations.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 36 / **P2.3-602**

## Radionuclide Isotopic Ratio Analysis at Ultra-Trace Concentration Levels for CTBT Applications

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Each anthropogenic emission possesses a unique radionuclide composition, serving as a ‘fingerprint’ that enables the identification of radionuclide contamination sources. This report presents a cutting-edge and rapid technique for radionuclide detection and source identification, focusing on ultra-trace concentration levels critical for detecting small-scale nuclear tests. Radionuclide isotopic ratios were measured using a high-resolution sector field mass spectrometer paired with a high-sensitivity APEX sample introduction system, complemented by the state-of-the-art ‘Ortec’ alpha spectrometer. Gamma spectra were recorded using the SILENA gamma-spectrometric system. Elevated isotopic ratio values, such as 137Cs/239,240Pu, 238Pu/239,240Pu and 240Pu/239Pu, provide reliable evidence of nuclear events and allow for source attribution when integrated with atmospheric transport modeling. The report also examines the occurrence of uneven ‘hot’ particle deposition and the formation of extensive ‘hot’ spots, emphasizing their significance in understanding radionuclide distribution and contamination patterns.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 37 / **P2.3-638**

## Detections of the short-lived 135Xe in the natural background of xenon isotopes in the soil

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The knowledge of the natural background of xenon radioisotopes in the ground is required to be able to distinguish it from any signals due to a potential underground nuclear explosion, as would be the case during an on-site inspection (OSI). The natural background of xenon isotopes from spontaneous fission in the soil has been studied during several measurement campaigns in Sweden. In most of these samples <sup>133</sup>Xe is detected. The method and logistics were improved during the latest campaign resulting in that also the short-lived isotope <sup>135</sup>Xe could be detected in multiple samples simultaneously with <sup>133</sup>Xe. This gives the potential to calculate the activity ratios, an important tool to distinguish between different sources. This is the first time, to our knowledge, that <sup>135</sup>Xe has been detected in the natural background in the soil. The method and results will be presented and compared with model predictions as well as a potential impact on noble gas collection and analysis in an OSI.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 38 / **P2.3-646**

## Atmospheric transport modelling analyzing source regions for recurring peak detections of radioxenon at RN38 and the Pacific

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A central challenge of radioxenon monitoring for the CTBT remains to classify radioactive xenon isotopes originating from reactor sources. This was also crucial for the interpretation of radioxenon

detections in the aftermath of the announced North Korean nuclear test explosions. Due to its geolocation, the IMS noble gas system at RN38 played a crucial role for that. At RN38, Takasaki, several episodes of recurring high radioxenon activity concentration peaks were observed in 2024/2025. Backward atmospheric transport modelling investigates the potential source region of those peaks by determining areas of coincident sensitivity. It is combined with backward ATM for some detections at other Pacific IMS noble gas stations.
Seasonal influence of Asian monsoon circulation changes the prevailing wind directions leading to different patterns in winter/summer months.
A comparison with operational ATM dispersion forecasts from the known North Korean nuclear test site assesses the impact of the recent elevated background concentrations on the IMS detection capability.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 39 / **P2.3-648**

## Measurements of radioxenon activities during periods of gaseous release from an Advanced Gas-cooled Reactor

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Xenon isotopes are relevant to the monitoring regime of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). We report radioxenon measurements data taken directly at source, deriving emission inventories for International Monitoring System (IMS)-relevant isotopes and isotopic ratios used to discriminate nuclear explosions from civil emissions. Time series activity plots have been produced from both in-core monitoring and direct measurement at the point of release using a stack monitor system. Ratio plots using both data sets have been produced with results compared to a commonly-chosen nuclear explosion 'discrimination line'. We will present a comprehensive study of radioxenon emissions from an Advanced Gas-cooled Reactor (AGR) and provide valuable radioxenon measurement data from a civil nuclear power plant (NPP). The reported data provides the first estimate of annual radioxenon discharges using direct measurements for an AGR and is an important step towards creating a reactor-type specific global emission inventory for NPPs.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 40 / **P2.3-680**

# Cocktail-DCC method to determine radio-isotopes quantities in fall-out

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Development of nuclear devices tends to take place in secrecy, without sharing specification of technical details. Tests are generally performed underground and unannounced. Seismics will announce a detonation and give an approximate location and time. One of the challenges of CTBTO is the reverse engineering of the specs of the nuclear device itself. After some containment time, noble gases will inevitably be set free and be detected by sampling stations. A key role in the source term estimation process is played by the ratios of the noble gases. These ratios provide a fingerprint of the material used in the device. In this presentation, we address this issue with the recently developed 'cocktail-DCC method'. For modeling the fall-out we use this tool, where nuclear decay and atmospheric dispersion are mathematically separated. This is done without loss of nuclide information at any time after detonation faster and in higher accuracy than before. We determine the change of radioisotope ratios over time for a set of reference source terms. Model results are compared with measured values. This contributes to an accurate estimate of the initial composition and yield of the device.

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# Comparison of Belgian and Dutch results from inverse ATMs for the nuclear detonation case of NPE 2024

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In case of an underground nuclear explosion (UNE), the waveform component of the International Monitoring System (IMS) that is being established by the Preparatory Commission of the Comprehensive Nuclear-Test-Ban Treaty allows for the determination of the location and timing of the event. To confirm the nuclear character of any UNE, the radionuclide component of the IMS searches for traces of radioactivity in the air. If relevant radionuclides are detected, atmospheric transport modelling can be used to potentially link these detections with the event of interest. In the framework of the National Data Centre Preparedness Exercise 2024, the Dutch and Belgian National Data Centres will present and compare their methods for linking radionuclide observations with a (fictitious) event of interest. It involves the use of SHERLOC (Dutch) on one hand, and IFS+FLEXPART and FREAR (Belgian) on the other hand. We will show the results of both methods and their comparison, both in terms of the atmospheric transport modelling part and in terms of the inverse modelling part. We aim to understand the origin of differences in the analyses, as this could allow us to identify which parts of the methodology could be improved.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 43 / **P2.3-692**

## Quantification of uncertainties in atmospheric transport modelling and their application to modelling radioxenon emissions

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Atmospheric transport and dispersion models (ATDM) are routinely used in the simulation of the global radioxenon background as well as in the localisation and characterisation of unknown radioxenon emitters. However, ATDMs contain uncertainties due to the assumptions made in the model setup as well as the chaotic nature of the atmosphere. Currently, quantification of these uncertainties and an exploration of the information they can add to the background simulation and source characterisation is limited. In this study we utilise stack monitoring data from European radioxenon emitters together with two ATDMs (NAME and HYSPLIT) and meteorological data from a meteorological ensemble to quantify the uncertainties associated with the transport of radioxenon to a SAUNA Qb placed in northern England as well as nearby IMS stations. The ensemble results are compared to the Qb measurements on a sample-by-sample basis to demonstrate the value considering uncertainties adds to the analysis of radionuclide detections and also to the identification of radioxenon sources.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 44 / **P2.3-702**

## What's new in the German Radioxenon network

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Bundesamt für Strahlenschutz (BfS) has been operating a network with weekly sample collection at 6-8 locations in Germany with sampling starting in 1977. Since 2024, this network is complemented by the automatic Xenon system Sauna Qb with a sampling period of 12h followed by automatic radioxenon analysis. The shorter sampling periods of the Sauna Qb promise a much better ability to characterize known emitters, evaluate ATM performance and localize unknown emitters. Here, we

present data from the operation of a Sauna Qb at two different locations in Bavaria. We compare the measured data with modelled radioxenon activity concentrations expected at the sites from forward and backward ATM. In order to localize unknown emitters detects and non-detects at several stations within reasonable proximity can be combined. The Qb is thus an ideal supplement of the existing networks, both nationally and internationally. We therefore carefully consider the location for a second Sauna Qb in Germany. We take into account locations of existing IMS noble gas stations and Sauna Qbs that are in operation around Europe and suggest to establish a common data sharing structure among Qb users.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 45 / **P2.3-712**

## Extended Radionuclide Background Campaign in Pabrade, Lithuania

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Since March 2021, the Pacific Northwest National Laboratory (PNNL), in cooperation with Radiation Protection Center in Lithuania, has been supporting a radionuclide background measurement campaign in Pabrade, Lithuania. This measurement campaign aims to provide a better understanding of background detections in a previously unobserved region. Lithuania is a complex region for measuring background radioactivity. Multiple known sources affect the region, including multiple medical isotope production facilities in Northern Europe and two recently constructed nuclear power reactors in Astravets, Belarus. The nearest International Monitoring System station is in Stockholm, Sweden, approximately 670 km away. PNNL has installed several environmental radiation detectors onsite, including the Transportable Xenon Laboratory (TXL). We present the results of the measurement campaign and discuss detection events where multiple radioxenon isotopes were observed in the region.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 46 / **P2.3-748**

## Characterization of Xenon-133 atmospheric civil source distribution using graph models on simulated data

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Xenon radionuclides atmospheric monitoring is part of the International Monitoring System, including multiple measurement stations, that were developed in the context of the Comprehensive Nuclear-Test-Ban Treaty. However, civil infrastructures, mainly nuclear power plants and medical isotope factories, constantly generate these radionuclides, creating a global atmospheric background. Previously, we developed a transport diffusion-based tool to simulate this background at the regional scale, but the discrimination with relevant signals is not straightforward. Here, we investigated, using four years of simulated data, how civil radionuclide concentrations are distributed over the stations, in terms of source range and similarities between stations. These source/station relationships are modelled through new defined variables and a graph structure, allowing the visualisation of a spectral clustering. Finally, applying a Graph Fourier Transform enabled a source separation of the station concentrations. The graph structure shows that stations can be clustered into 11 regional groups, each one with a center of one to four stations that does not vary with seasonality. Also, the source separation provides maximum absolute errors below 0.1 mBq/m^3, lower than sensors detection limit, for most of the stations. These results highlight the potential of such simulations for anomaly detection.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 47 / **P2.3-774**

# Possible source origin of cesium-137 detections at station MXP44 in 2024

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The International Monitoring System stations may occasionally detect radionuclides relevant to the CTBTO. Such is the case of station MXP44, which is located in Guerrero, in the Mexican state of Baja California. Cesium-137 was detected three times in the year 2024 with a level 4 categorization. The objective of this work is to estimate the possible source origin of the cesium-137 detections. Therefore, back trajectories were simulated using the HYSPLIT trajectory model at 500 m altitude. The RNToolkit web application tool was used to determine the periods in which cesium-137 was detected at that station and the level of the categorization. The simulations showed that the possible source origin of these detections were episodic emissions from the Diablo Canyon nuclear power plant located in the United States of America. Because of the wind dominance from northwest, an advection of stable air mass coming from the Pacific. The air masses took approximately between four and three days to arrive at the station. These results also indicate that the MXP44 station would contribute to evaluate the evolution of the emissions in the event of an accident at the Diablo Canyon nuclear power plant.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 48 / **P2.3-779**

## Investigating unusual high-level radioxenon detection episodes at several locations of the IMS NG network: causes, origins and implications for radioxenon monitoring

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The International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) operates a global network of stations designed to detect potential violations of the CTBT. As a critical part of this system, the noble gas (NG) network plays a major role for the monitoring of radioxenon isotopes. Recently, extended episodes of elevated concentrations of radioxenon were recorded at several IMS locations, including the IMS NG systems at Takasaki (JPX38) and Wake Island (USX77), as well as the non-IMS system at Horonobe (JPX81). These detections significantly exceeded historical levels of radioxenon at these sites, reaching up to 80mBq/m3 of Xe-133 at JPX38, and, in some instances, included all the four CTBT-relevant radioxenon isotopes. This presentation aims to explore these unusual high-level detection episodes, investigating their causes and origins, while discussing their implications for the monitoring of radioxenon.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 51 / **P2.3-820**

## Comparative Analysis of CFD Simulations and CTBTO Monitoring Data for Radon Displacement Detection in UNE Scenarios

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Radionuclide monitoring is one of the CTBT verification technologies that measures radioactive particles and noble gases generated by nuclear explosions. Detecting underground nuclear explosions (UNEs) is challenging as these events are unlikely to release radioactive particles into the atmosphere. To address this, monitoring noble gases more likely to escape into the atmosphere has been proposed for additional confirmation of seismic events. This paper builds on the hypothesis

that UNEs can induce radon displacement (222Rn and 220Rn) towards the surface due to subsurface pressurization.

Building upon the foundational work by Jonathan L. Burnett, Timothy L. Stewart, Martin E. Keillor and James H. Ely (2021), this study conducts a comparative analysis of Computational Fluid Dynamics (CFD) simulations and real-world radon monitoring data obtained from the Comprehensive Nuclear-Test-Ban Treaty Organization. CFD modeling is employed to simulate radon transport dynamics under varying geological and environmental conditions, aiming to replicate scenarios where UNEs may cause detectable radon anomalies. These results are compared against historical data from CTBTO monitoring stations to evaluate the consistency between modeled predictions and observed radon displacement patterns.

This work examines the potential and limitations of CFD modeling as a complementary tool for interpreting radon anomalies detected by CTBTO stations.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 53 / **P2.3-837**

## Detections at Regional IMS NG Station and ATM Tracking of Possible Emission Source

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The nuclear nature of any explosion occurrence under the CTBT can be determined/established using the detections of any relevant radionuclides at IMS stations. This plays an essential role in the compliance monitoring of the Treaty. During an explosion, Radionuclide materials, specifically radioxenon gases, can be carried in the atmosphere or vented from underground or underwater source. Since radioxenon isotopes can be produced from various sources, there is the need to monitor background activity concentrations in the environment to enable good discrimination of potentially abnormal levels of detections which are of treaty relevance.
Of interest in this study are the radioxenon detections in 2020 at CMX13 noble gas station (in the subregion) and the possible sources contributing to the observed detections. Analyses of daily samples collected at the station for 2020 showed that 0.6% of the 312 samples measured anomalous radioxenon detection. Xenon-133 was the only abnormal detection of concentrations <1.0 mBq/m³ in January 2020. Backward ATM modelling of the emissions origin indicates that PSR is around industrial Xe emitting facility in South Africa, the only major emitting source in the region around station CMX13 with significant impact on detections depending on meteorological conditions.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 54 / **P2.3-840**

# Exploring bounding parameters for modeling subsurface transport of radioxenon

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Underground nuclear explosions produce radioxenon, which may be transported through the geology and subsequently collected and measured locally in an On-Site Inspection or regionally via the International Monitoring System. Predicting how much radioxenon may be available for collection and measurement requires development of geology-specific subsurface gas transport models to estimate timing and quantity of gases released. These models are increasingly complex, incorporating explosively driven transport through crushed or damaged rock zones, models of naturally occurring heterogeneities in geologic media, chemistry at interfacial surfaces, and both porous media and fracture driven flow. In this work, we explore a model that can be used to help set practical bounding parameters for these subsurface transport simulations. For example, physical phenomena that do not result in sufficient radioxenon concentrations in the appropriate time frame for nuclear explosion monitoring can be excluded from the models. We explore these bounds for selected emplacement conditions for a nominal 1 kT explosion.

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**P2.3 Atmospheric and Subsurface Radionuclide Background and Dispersion** - Board: 55 / **P2.3-847**

# Temporal Trends Assessment of Atmospheric Radionuclides in Kuwait: A Long-Term Study

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Many Arab countries in the Middle East face negative impacts from dust fallout, which includes both natural and human-made radionuclides. This study thoroughly analyses long-term atmospheric radionuclide levels in Kuwait. Over ten years (2013–2022), daily measurements of natural and anthropogenic radionuclides—specifically 137Cs, 7Be and 40K—were collected using the RN40 station. The average concentrations found were 10.51 ± 2.04 μBq m−3 for 137Cs, 11.8 ± 3.7 mBq m−3 for 7Be and 161.7 ± 3.8 μBq m−3 for 40K. The concentration of 7Be in Kuwait aligns with global averages. The level of 137Cs is consistent with earlier reports, although an unusually high value of 407 μBq m−3 was recorded, surpassing previous maximums by 62%. The peak in 137Cs concentration coincided with increased dust storm activity, particularly in 2018, which saw 18 dust events. Dust resuspension, influenced by northwesterly winds during summer, likely transported 137Cs-laden particles from surrounding areas. The detection frequency of 137Cs (10.33%) was similar to previous findings in Kuwait, despite expectations of a decline due to radioactive decay. This suggests that factors such as heightened dust storm activity and reduced rainfall may have contributed to the ongoing presence of 137Cs in the surface air in Kuwait.

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**Online e-Poster Session 2** - Board: 0 / **P2.4-066**

## Analog geophysical data [from nuclear tests]: Which digitization software should I use? How can I leverage the power of AI for forensic analysis of analog data?

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Digitization of historic analog seismograms from nuclear explosions is an imperative need for the Nuclear Explosion Monitoring community since most recorded observations of nuclear tests are in analog media and conversion to digital format is resource and time intensive, which requires specific expertise. To assess the effectiveness of available digitization software, we identified four potential algorithms (out of 33 reviewed references) for further testing and developed a Python toolkit for the generation of synthetic analog helicorder records (synthetic generator). Our evaluation of the selected digitization software uses a tiered approach: synthetic records; scanned and previously digitized data; and scanned, undigitized data. The synthetic generator creates data in a manner that faithfully represents the characteristics (and challenges) of analog seismograms: variable trace thickness, time marks (WWSSN, USSR), waveform crossover, etc. As the number of underground nuclear tests conducted during the digital data era is comparatively small, we can use our synthetic generator to produce and augment AI/ML training datasets for machine learning applications. We present our initial results for testing of the selected digitization software packages using synthetic data generated by our toolkit and explore potential applications for nuclear monitoring of data created by our synthetic generator.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 24 / **P2.4-068**

## Vectorial Digitization and Re-Analysis of Turkey's Legacy Seismic Records: Four Major Historical Earthquakes

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Kandilli Observatory and Earthquake Research Institute (KOERI) was established in the 1800s during the Ottoman Empire as the Imperial Observatory and has conducted observations in meteorology, astronomy and seismology for over a century. KOERI expanded its seismic network and ability to determine earthquake parameters, evolving with advancements in seismology. Over time, it built a rich database in seismology, astronomy, and meteorology, making it a prominent institution with a rich legacy of scientific observations. We have been digitizing historical earthquake seismograms to

construct a historical earthquake database at KOERI since 2009, gaining expertise in vectorization and overcoming related challenges. We have analyzed the 1912 Ganos, the two 1935 Erdek-Marmara Island, and 1963 Çınarcık Earthquakes in the Marmara Region by digitizing analog seismograms and applying modern seismological methods to these digitized records to determine seismic parameters, including seismic moment, moment magnitude, radius of the circular source zone, and stress drop. We also determined epicentral locations using historical seismic data, such as original records and station bulletins, and identified fault mechanisms applying moment tensor inversion to digitized seismograms.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 25 / **P2.4-145**

## A Federation of Online Legacy Data Centres in Seismology (FOLDS)

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FOLDS is a system being developed enabling seismological data centres with legacy data collections to create, curate and distribute standardized metadata and image files related to analog seismic records. The system will promote data reuse, following FAIR principles, leveraging a new suite of International Federation of Digital Seismograph Networks (FDSN) web services similar in capability to the current FDSN services supporting digital timeseries. These services will allow access to metadata and digital representations of analog recordings by Internet through a federation of data centers operating the FOLDS system. This allows a distributed approach to the generation of the metadata as well as distribution of digital images and metadata. Data can be replicated in multiple centres if desired.

A key part of FOLDS was the identification of 19 Required, 25 Recommended, and 12 Optional elements of metadata needed. FAIRness considerations were identified for Required elements. This process kept the workload reasonable but ensures data usability.

Currently 12 geographically distributed legacy data centres have agreed to participate as beta testers of the system. The resulting collection of standardized metadata and web services will greatly contribute to legacy data availability.

This presentation identifies the status and next steps in FOLDS' development.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 28 / **P2.4-158**

# Peaceful nuclear explosions at Azgir Test Site (West Kazakhstan)

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Between 1965 and 1987, 39 peaceful underground nuclear explosions were conducted by the USSR on the territory of Kazakhstan, 17 of them at the Azgir Test Site, located in Western Kazakhstan. The Test Site is located on the Bolshoi Azgir salt-dome uplift, on the western part of the Pre-Caspian saline province located north of the Caspian Sea. At the Azgir Test Site, for research purposes, in order to work out the technology of creating underground cavities for various purposes, the peaceful nuclear explosions (PNE) were carried out in the rock salt massif (1966-1979). As a result, 9 underground cavities of different volume and depth were created.
The report considers the dynamic and kinematic parameters of PNE records conducted at Azgir, recorded by seismic stations on the territory of the USSR (the CSE network of IPE RAS) at epicentral distances from 770 to 6500 km. A total of ~300 historical analogue seismograms were measured. In addition, data on the geological and tectonic settings of the test site were collected as well as on the current state of the technological sites where the tests were conducted. The manifestations of modern seismicity in the vicinity of the Test Site were investigated.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 27 / **P2.4-252**

# From Paper to Pixels: Lessons Learnt from Creating and Using the NELD Repository

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The Nuclear Explosion Legacy Data (NELD) Repository was designed and built to store analog scanned and digitized data in a format consistent with the CTBTO PrepCom database. It follows and extends the CSS/IMS formats for the time series data and station metadata. NELD repository includes over 2,000 scanned seismic recordings but can be easily extended to a digital waveform repository. Scanned data cover over 300 nuclear explosions detonated in test sites around the world and recorded at over 60 European stations in Austria, Bulgaria, Republic of Moldova and Romania. The repository is supported by a database including information about the event, station, equipment and analog recording. Valuable experience was gained on procedures for data selection and scanning, and for collecting, organizing and storing the metadata information needed for successful usage of legacy data. Digitization software packages openly available were tested on some of the scans. All scanned data and metadata are stored in the Nuclear Explosion Legacy Data (NELD) repository designed by Leidos, with similar structure as the IDC database and are ready to be shared with the community.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 34 / **P2.4-271**

## Insights on the Seismogram Database at the Timisoara Seismological Observatory, National Institute for Earth Physics, Romania

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The Timisoara Seismological Observatory has a history of over 120 years and contributions to the early stages of seismic monitoring in Europe. It hosts a well-preserved collection of seismograms dating from the early 1950 until the late 2000. During the process of sorting and indexing chronologically the seismogram collection, recordings of nuclear tests on different types of instruments were identified.

National Institute of Earth Physics (NIEP) contributed to the Nuclear Explosion Legacy Data (NELD) repository with data from the archive of NIEP headquarters, that includes 80% the Romanian stations active in the study period (1950-2000).

A considerable volume of data on nuclear tests recorded at the seismic stations located in the Western part of Romania and stored in the archive of the Timisoara Observatory are yet to be added in the NELD repository. Such recordings were obtained from the seismic stations at Timisoara (TIM), Buzias (BZS), Susara (SSR), Gura Zlata (GZR), Banloc (BAN) and Siria (SIRR). In addition to identifying the recordings of interest and scanning them, metadata information is being gathered on the seismic stations and their instruments. Same procedures are applied as for NIEP's earlier contribution to NELD.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 29 / **P2.4-354**

## Reviewing Ground Truth Event Selection

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The IASPEI Reference Events List, referred to as the "Ground Truth" (GT) event list, is a database of earthquakes and explosions where the epicentral location is known to a confidence of within 10 km. GT events support nuclear test monitoring and the mission of the Comprehensive Nuclear-Test-Ban Treaty by aiding NDCs in improving event location accuracy. We will present a new Preliminary GT list, consisting of 78,886 events with improved geographic coverage, obtained by updating the GT criteria. The current GT criteria, proposed by Bondar and McLaughlin (2009), requires at least one station within 10 km of the event, and a station distribution that has a maximum secondary azimuthal gap of 160° and a ΔU (the station distribution in the local area) of less than 0.36. In attempting to add additional seismic phases to existing GT events we find that it is possible to improve the number of local stations and the secondary azimuthal gap for an event but degrade the ΔU. Given this finding and the improvements in modern location algorithms in dealing with unbalanced station distributions, we have reassessed these criteria leading to an increase in the number of GT events identified and their geographic distribution.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 31 / **P2.4-426**

## Progress on digitization and recovery of historical U.S. nuclear test seismic data

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For the past several years, Sandia National Laboratories (SNL) has been working to digitize, recover, and calibrate seismic data from its archive of hundreds of analog magnetic tapes. These tapes are original archives from the historical nuclear testing era, some dating more than 60 years old, and contain analog waveforms of regional seismic data of historical U.S. underground nuclear tests recorded on seismic stations of the Leo Brady Seismic Network. This effort has so far culminated in the release of 1,297 newly digitized seismic waveforms of 20 historical U.S. underground nuclear tests between 1966 and 1972. In 2024–2025, we have had further effort to digitize and recover more seismic data from these tapes. In this presentation, we will show the latest results of the digitization and recovery effort, as well as lessons learned from the recovery and calibration process.

SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 37 / **P2.4-427**

## Developing workflows for seismic patrimony

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The discovery and vectorization of legacy seismic data are two of the barriers to the (re)use of seismic data recorded on physical media. Challenges to use include imaging the large numbers of records, metadata discovery and curation, and the creation of time series accessible to modern processing methods. Here we describe and demonstrate progress on the development of an open source web-enabled data pipeline that aligns with FAIR practices and incorporates FDSN data exchange standards for legacy seismic data. The project workflow begins with the digitization of seismograms from the Caltech Seismological Laboratory, though any image can be utilized. The image will be uploaded to the Archiverse platform which will be configured to extract and curate recorded station metadata as well as researcher annotations. The project build upon the open-source SKATE (https://seismo.redfish.com/#/) platform for vectorization, which can be used by any researcher with an internet connection. As the project is in its early stages, we seek input for developing a robust tool which will meet the needs of a broad range of researchers and contribute to the growing knowledge of FAIR practices in seismic legacy data curation.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 32 / **P2.4-588**

# Features of the Wave Pattern of Historical Atmospheric Nuclear Explosions According to the Data of Central Asian Stations

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A large number of records of nuclear tests conducted at various test sites and different environments around the world remain in the archives of historical analog seismograms in the Seismological Agencies of Central Asian countries. At the same time, not enough attention has been paid to the study of the features of the wave pattern of atmospheric nuclear explosions in comparison with underground nuclear explosions. The available legacy records are extremely important in connection with the task of nuclear tests detection and discrimination within the framework of the CTBT-related activity, creation and calibration of a database of reference events for the current IMS stations, and other tasks. An analysis of the dynamic and kinematic parameters, using historic seismic and infrasound records, of atmospheric nuclear explosions conducted at the Lop Nor (with a maximum power of Ymax=4 Mt), the Semipalatinsk Test Site (Ymax=1.6 Mt) and the Novaya Zemlya Test Site (Ymax=58 Mt), is presented in the report. A comparison (at regional and teleseismic distances) of waveform patterns was made for tests conducted in the atmosphere, on the surface and underground.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 33 / **P2.4-675**

## Spatio-temporal variations of short-period S wave attenuation field in a region of the North Korea Punggye-Ri nuclear test site

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Six underground nuclear explosions (UNEs) were conducted at the DPRK nuclear test site in 2006-2017. Magnitudes of these events varied from 4.3 to 6.3. We analyzed seismograms of UNEs and near earthquakes, obtained by stations MDJ and VLA at distances of ~270-450 km to investigate characteristics of the attenuation field. We studied the ratios of maximum amplitudes of Lg and Pg waves (Lg/Pg parameter). Narrow-band filter with central frequency of 1.25 Hz was used. According to the UNEs data, Lg/Pg parameter diminished essentially from 2006 to 2017. We processed several recordings of earthquakes with epicenters near the Punggye-ri test site. It was shown that in 2017-2024 the mean value of the Lg/Pg parameter for the earthquake recordings is higher essentially than for UNE data in 2017. We compared the new data with data obtained earlier for the Semipalatinsk test site (STS). The mean value of the Lg/Pg parameter for the Balapan area in the STS diminished also essentially from 1980 to 1989. The most natural explanation of temporal variations of the attenuation field connected with ascending deep-seated fluids from the uppermost mantle into the earth's crust as a result of intensive influence of the powerful UNEs on the geological medium.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 26 / **P2.4-747**

## Enhancing the Nuclear Explosions Waveform Repository: Integrating Data Contributions from National Institutions and Networks

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The 'Waveforms From Nuclear Explosions (WFNE)' repository includes detailed information (origin, bulletin, other geophysical data) on all the 2,157 atmospheric, underground and underwater nuclear explosions detonated in the world between 1945 and 2017. Over 146,600 waveforms recorded at 343 stations in 78 countries are associated to 1,109 of the nuclear explosions, ranging from digitized analog recordings for the oldest explosions to recent IMS data, as well as their station/instrument information. Users can search, visualize and download data of interest for their research. The repository was developed and is maintained by Leidos under DTRA sponsorship. It was built as a trusted data set, starting from the previous data repository 'Nuclear Explosion Database (NEDB)'. Waveform

data and geophysical information were added, as collected from many open sources, such as FDSN, EIDA, CTBTO PrepCom, ISC and legacy data sets of digital data or digitized analog recordings assembled by different institutions, after completeness and quality checks were performed. One of the latest additions is the large Blacknest British array data set. Data collection continues, other datasets are already identified and prepared to be merged in WFNE. Submission of digital/digitized data of nuclear sourced waveforms is requested from WFNE users and institutions willing to contribute.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 35 / **P2.4-841**

## Reoccupying Historic Stations and Comparing Measurements for Enhanced Characterization

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The historic nuclear test sites of the world provide a key resource in legacy seismic measurements. Many of the seismic recording stations in place for historic tests have been abandoned as new locations have been established. We deployed sensors equivalent to those installed in the 1980s with modern equivalents at historic seismic station locations to compare measurement and site characteristics. In the process of trying to locate and reoccupy these historic sites we have undertaken a difficult task due to the lack of documentation. We continue to identify sources for the emplacement conditions, but modeling suggests that reoccupations within 100 meters should be adequate for most comparisons. We present some of the initial comparisons of data and lessons learned from redeploying these stations.

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**P2.4 Historical Data from Nuclear Test Monitoring** - Board: 36 / **P2.4-886**

## Bulletin of the Central and Eastern European Infrasound Network 2023-2024

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The Central and Eastern European Infrasound Network (CEEIN) was established in 2018 as a co-operative initiative among research institutions in Czechia, Austria, Hungary and Romania, with Ukraine joining in 2019. Currently, CEEIN consists of 10 infrasound arrays, making this a dense network with great monitoring capabilities. This study presents the biannual CEEIN bulletin for 2023 and 2024, continuing our previous work on regional infrasound monitoring. The bulletin includes both seismoacoustic events (e.g. quarry blasts) and infrasound-only detections (e.g. eruptions of Mount Etna). Seismoacoustic events are re-located using the iLoc algorithm to improve spatial accuracy. By systematically cataloguing and analyzing these events, the CEEIN bulletin supports regional monitoring efforts and fulfills the need for datasets that can serve as a foundation for future studies.

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in-person

**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 20 / **P3.1-063**

## A dense nodal array in Cartago, Costa Rica defines ground truth events and enables stacking of teleseismic waveforms from potential nuclear test explosions

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To contribute to the identification and mapping of active faults and their geometries in and around Cartago, Costa Rica, scientists from the Costa Rica Volcanological and Seismological Observatory at the National University (OVSICORI-UNA) and from the United States Geological Survey (USGS) have joined efforts to install and operate an urban, dense array of seismic nodes. The network consists of 70 short-period three-component nodes on a grid with an average spacing of about 2 km. This network was installed in July 2024 and will operate until April 2025. The high rate of seismicity in Cartago and its surroundings ensures recording and location of numerous local events with magnitudes also to be recorded by OVSICORI-UNA's permanent seismic network. This dense network can record events at regional and teleseismic distances. Earthquakes within the network will be located with uncertainties in locations of a few hundred metres and depth of less than 1 km. We expect to have a significant number of ground truth events added to our seismic catalogue, which can be used for station corrections. This dense array will be useful for stacking waveforms from earthquakes and potential nuclear explosions at teleseismic distances. We will be presenting preliminary results from this array.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 21 / **P3.1-102**

## VNIIA experience in seismometer development

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VNIIA is a leading company of Rosatom State Atomic Energy Corporation in CTBT implementation, which currently performs a range of research. Three types of new seismometers of the VNIIA family were designed:
- A seismometer Type 1 – a vertical short-period seismometer for installation in boreholes;
- A seismometer Type 2 – a three component broadband seismometer for installation on a pedestal;
- A seismometer Type 3 – a three component broadband seismometer for installation in boreholes.
This document provides a comprehensive overview about VNIIIA seismic equipment development, and includes useful background information as well as a lot of technical details.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 22 / **P3.1-167**

## Infrasound sensors calibration by laser pistonphone down to 1mHz

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Infrasound can be detected in nature and human activities, such as earthquakes, volcanic eruptions, mudslides, supersonic flight, etc. The monitoring of infrasound sound pressure signal mainly depends on the infrasound sensor, and the accurate measurement of infrasound sound pressure mainly depends on the calibration of the infrasound sensor.
Since the NPL developed laser-pistonphone to calibrate microphone, laser pistonphone became a feasible device in infrasound calibration. In this paper, a infrasound laser pistonphone was developed down to 0.001Hz, including an infrasound sound pressure generator, feedback control and infrasound excitation system, data acquisition conditioning system and ultra-low frequency laser interferometer.
Furthermore the external environmental noise will interfere with the atmospheric pressure in the cavity of the infrasound generator, which will affect the waveform generated by the infrasound generator and produce interference and waveform distortion. A differential noise reduction system was used in this device in order to obtain infrasound time-domain waveform from 0.001Hz to 20Hz with lower fluctuation.

A Mb3a infrasound sensor was calibrated by this device from 0.01Hz to 31.5Hz, and the result fit the company calibration data very well.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 23 / **P3.1-178**

## Challenges in seismometer electrical calibration: A case study preparing for a station recapitalization

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Seismometer electrical calibration at IMS stations has long been depended upon to ensure the accuracy of seismometer performance. At best, electrical calibrations provide confidence that the seismometer performance has not changed since the time of installation. However, as an absolute measure, electrical calibrations may not result in a sufficiently accurate or traceable measure of seismometer performance, even when accounting for the manufacturer provided response models. As an example, we consider the instrumentation configuration for the planned recapitalization of the primary seismic station PS47, NVAR. The NVAR array is comprised of multiple elements with short-period Geotech GS13 seismometers in boreholes and recorded on Geotech Smart24 digitizers. The plan is to replace the Smart24 data recorder with a high-gain Nanometrics Centaur digitizer. Here we show the results from a primary traceable calibration of a GS13 seismometer from NVAR to validate the nominal response, confirm the influence of the digitizer replacement on the seismometer performance, and quantify the impact of these changes on the electrical calibration.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 24 / **P3.1-182**

## Impact of temperature on GS-13 seismometer calibration results

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The impact of temperature variability in the environment of a seismometer has the potential to affect its operating performance and should be well understood for sensors within the IMS. In this study,

GS-13 passive seismometers are collocated with broadband CMG-3T seismometers at two seismic sites near Sandia National Laboratories' FACT site. The operating temperatures of the seismometers are continuously recorded while the sensors undergo daily electrical calibrations. These datasets allows us to measure how temperature impacts the electrical calibration results as well as the sensors' actual response to ground motion. We compare our measured temperature coefficients for the GS-13 sensors to those predicated by colleagues at Natural Resources Canada (NRCAN) who conducted a study on how temperature impacts the operation of the S-13 seismometers in the YKA seismic array.

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**Online e-Poster Session 1** - Board: 0 / **P3.1-233**

## The Role of Instrument Depth in Seismic Signal Quality: Findings from a Vertical Array at Glasgow Observatory

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Seismic data from the International Monitoring System (IMS) captures both natural and environmental noise, along with signals from seismic events such as earthquakes or potential explosions. While most of these stations are surface-based, a few instruments are deployed at depths ranging from tens to 100 meters. Although previous studies suggest that deeper instrument deployment may improve signal to noise ratios (SNR), this enhancement is not always consistent, and no universal pattern has been established. Understanding how instrument depth affects noise and SNR can inform more effective IMS station design and network planning, ultimately improving event detection and characterization. In this study, we analyze a unique dataset of identical broadband instruments deployed at various depths within the same borehole, ranging from approximately 30 to 200 meters. This configuration isolates the effect of depth on seismic signals. By examining both background noise levels and event detection capabilities across a range of frequency bands, we find that while noise levels generally decrease with depth, as reported in other regions, improvements in seismic signal quality and SNR do not always follow the same trend.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 25 / **P3.1-300**

## The Role of Small Seismometers and Infrasound Sensors in On-Site Inspection (OSI) Verification for the CTBT

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Emerging small seismometers and infrasound sensors hold transformative potential for strengthening the CTBT verification regime. These portable, relatively inexpensive instruments provide high-resolution data that are essential for the detection and location of events that may indicate nuclear testing. Unlike traditional equipment, they are more affordable and accessible, allowing deployment in diverse and challenging environments. Their integration into OSI enhances event characterization by reducing uncertainties and enabling rapid, reliable data acquisition.

This study will explore a range of small seismic and infrasound equipment, focusing on their operational advantages, affordability and innovative design. By analyzing real-world applications and case studies, it will highlight their potential to complement existing verification systems.

The scalability of these technologies will be considered in terms of their potential contribution to enhancing OSI mission efficiency and effectiveness.

It will also investigate how these tools can expand the participation of young scientists in CTBT verification, especially from underrepresented regions, through training activities. Small sensors push technical boundaries and open up more accurate and inclusive verification possibilities.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 44 / **P3.1-304**

# Ice Cover Monitoring with Distributed Acoustic Sensing (DAS)

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Ice cover monitoring has been recognized as a critical task in environmental studies for hazard mitigation and critical alerts reporting. Current observation methods of changeable ice thickness often fall short in terms of accuracy, completeness and cost efficiency. Distributed acoustic sensing (DAS) uses fiber optic cables as sensitive elements and presents a promising alternative to the traditional point based seismic deployments providing affordable capabilities for real time ice cover monitoring over extended areas, specifically along the coastlines.

We report our experimental results aimed at evaluating the efficiency of the DAS system for ice active monitoring at the Klyazma Reservoir. The study involves comparison of the DAS hardware performance with the co-located geophones in reconstruction of dispersion curves for flexural-gravity waves by using data analysis based on inversion methods. Inferred dispersion presents a snapshot of the ice condition, its thickness and elastic properties.

The DAS monitoring approach consents application of both active (source based) and environmentally friendly passive monitoring techniques based on the ambient noise imaging. The results indicate that the DAS system can effectively capture temporal changes of the ice properties, thus contributing to the environmental monitoring and providing information to develop resilience strategies in response to climate changes.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 26 / **P3.1-311**

## Laboratory experiment for sustainable pressure observation at the seafloor

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A pressure gauge at the seafloor is key sensing instrument for geophysics and oceanography. Pressure change over time can be consent to the seafloor deformation associated with plate convergence in the plate subduction zone or the magma injection near the submarine volcanoes, etc. It is also suggested that pressure change at the seafloor can be partly reflected by the ocean current variations, e.g. the Kuroshio merenda in Japan. On the other hand, sensor drift, i.e. offset from the standard pressure, is observed in pressure gauge, whose rate is sometimes larger than the *in situ* true pressure change. Therefore, a stable pressure gauge should be selected for long-term continuous observation to perform quantitative pressure measurement. The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has developed the seafloor observatories network known as DONET, long-term borehole observatory system (LTBMS) or campaign-typed pressure sensing system in the past, which are composed of pressure gauges. All pressure gauges were pressurized by a pressure balance with equivalent static pressure to an installed water depth before deployment. This experimental procedure allowed us to determine which pressure gauge was best suited for *in situ* measurement. Screening of the better sensors can reflect to the more sustainable *in situ* observation.

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## Benefits of Rotational Ground Motion Measurements for OSI Activities

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The seismic wave field is fully described by six components: three components of translation and of rotation (6 degrees of freedom, 6-DoF). As rotational amplitudes are small, for a long time seismology confined itself to half of the available information by using only translation. However, since roughly two decades, rotational ground motions are observable. Since a couple of years, even portable sensors exist. Although the methods used for OSI activities are stipulated, we want to show how they might profit from the inclusion of rotational measurements. These benefits include: determining structural models, especially for the shallow sub-surface (site characterisation), which in turn improve event localisation; dynamic tilt correction of horizontal translational components; wave field decomposition by 6-DoF polarisation analysis; improved resolution of seismic moment tensors; overcoming long-standing problems in active seismic experiments such as coherent-noise suppression and sampling requirements. Probably the most important aspect is the fact that with new processing techniques we can obtain similar information from a single 6-DoF station where traditionally an entire array of translational sensors would be necessary. Therefore, efforts in terms of hardware, maintenance, human power and time can be reduced drastically. All these are key factors in OSI activities.

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**Online e-Poster Session 1** - Board: 0 / **P3.1-376**

## Will Distributed Acoustic Sensing (DAS) be able to replace classical seismic instruments?

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The field of geophysics is seeing rapid development of new technologies, including Distributed Acoustic Sensing (DAS). This innovative technique attracts scientists and researchers for its ability to monitor and analyze geological and structural changes with high spatial resolution over large distances. Unlike traditional methods based on the use of stationary instruments, DAS allows to make data acquisition using a distributed network of sensors, which opens up new horizons for studying complex geophysical phenomena. Traditional geophysical instruments, although they have proven themselves over many years, often have limitations related to their mobility, accuracy and cost. In the conditions of the modern world, where monitoring and safety requirements are becoming increasingly stringent, there is a need to develop new approaches that could provide greater efficiency and flexibility in conducting geophysical research. DAS, due to its scalability and adaptability, is one of such alternatives. However, DAS technology is not ideal and a natural question arises: will virtual geophysical instruments based on optical cables really be able to replace traditional geophysical instruments in fundamental research in the future? The presented work attempts to answer this question, considers the basic principles of DAS operation, its advantages and disadvantages, and compares virtual seismic sensors with classical seismometers.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 28 / **P3.1-378**

## Advancing Explosion Monitoring with Distributed Acoustic Sensing: Insights from the NORFOX Fibre Array

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Distributed Acoustic Sensing (DAS) is revolutionizing seismology by repurposing existing and purpose-built fibre cables as seismic sensors. While DAS faces challenges, such as higher noise levels and single-component limitations compared to traditional sensors, it offers significant advantages. These include extensive sensing lengths, high sensor density and fine spatial resolution. Curved cable paths further enhance sensitivity to various wavefield components, and integrating DAS with telecommunication infrastructure can strengthen traditional seismometer networks for regional explosion monitoring. This study explores the use of DAS for array-based beamforming to improve phase identification and signal-to-noise ratios. Data from the NORFOX fibre array in southern Norway, featuring five curved cable arms with a 3 km aperture, are compared to the co-located NORES broadband seismic array. Recordings of local and regional earthquakes, surface explosions and thunderstorms show clear P, S and acoustic arrivals. These events inform the development of array processing techniques, including Frequency-Wavenumber analysis, to estimate slowness and back azimuth of phases. DAS-specific factors like sensor directivity are addressed to optimize monitoring for different phase types. NORFOX demonstrates the potential of DAS as a powerful tool for explosion monitoring.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 29 / **P3.1-415**

## Wind Noise Reducing System Technical Solutions Tailored to the IMS Network

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Over the years, Enviroearth has developed Wind Noise Reduction Systems (WNRS) of advanced technologies based on comprehensive CTBTO requirements and configuration range over the whole IMS infrasound station Network.

This work involves the continuous implementation of new manufacturing methods, installation processes and accessories' technical innovation, making it adaptable to any situation (for both total or partial system upgrade) with an emphasis on the robustness and durability under extreme environment.

The continuous development can be illustrated by various case studies and projects involving atypical civil engineering and site preparation, inlet ports valves extension's improvement, optimization of the WNRS gooseneck production method, robustness comparison study of different metals…

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 30 / **P3.1-457**

## Low-Cost Digitizer Based on FPGA and Raspberry

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Ecuador is a country surrounded by a great variety of natural hazards. Hence, it is necessary to carefully watch seismic and volcanic activity within the country, which requires a great number of resources. The Geophysical Institute of EPN (IG-EPN) oversees monitoring activities in the country, however, budget is usually a problem. With over 300 monitoring sites, IG-EPN must manage the way of having everything working properly. Therefore, a low-cost digitizer based on FPGA and Raspberry was developed. It is intended to provide an economic way to obtain seismic signals transmitted to the monitoring center.
The device has first been tested on nearby locations such as Cotopaxi volcano, which is two hours away from IG-EPN headquarters. It has shown a good performance in this environment which can achieve very low temperatures. It has been tested on the lab, where it achieved proper local storage and ethernet transmission. Therefore, with further development, it is intended to help first with lahar detection activities.
In conclusion, this work addresses a problematic situation where low-income countries struggle to have an adequate monitoring system operating in their countries.

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## Observing the oceans and Earth with submarine cables: SMART

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The ocean is key to understanding climate change, sea level rise, tsunamis and earthquakes. The ocean is difficult and costly to monitor. Over the last decades, dedicated submarine cable systems have been supporting science and early warning, as well as monitoring for nuclear test explosions.

The Science Monitoring And Reliable Telecommunications (SMART) Cables Initiative is working to integrate sensors into commercial telecom cables. These sensors will share the power and communications global infrastructure of undersea cables at modest incremental cost. The UN ITU/WMO/UNESCO-IOC Joint Task Force (JTF) is facilitating the adoption and implementation.

Sensors include temperature, pressure, and seismic motion. Data will improve ocean heat content and circulation and sea level rise estimates, global tsunami and earthquake warning networks, and geophysical understanding of the earth. They can help protect the cable from natural and anthropogenic hazards.

We describe the SMART initiative with more detail on two systems, Tamtam connecting Vanuatu and New Caledonia, and Atlantic CAM connecting Lisbon (the Continent), Azores and Madeira in a 3700 km ring with SMART nodes along the cable, both to be installed in 2026. Opportunities for further developments to improve both ocean observing as well as cable protection and security will be discussed.

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# Field calibration of seismic instruments

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Initial calibration can be done in a laboratory using specialized test equipment, but to check calibration of instruments over their lifetime in the field requires different processes. We discuss two particular challenges: site response and temperature sensitivity.

A method for field calibration with respect to a portable reference sensor has been demonstrated by Michaela Schwardt. This works well when sensors can be co-located. However, for borehole stations where the reference is at the surface, the difference in site response with depth must be taken into account. One solution is to install a permanent reference sensor downhole, co-located with the primary sensor. This has already been done (although for a different reason) in borehole networks that include both strong and weak-motion sensors downhole. We present data from the Taiwan DSO Network showing high coherence for pairs of downhole instruments.

Temperature dependence of instrument sensitivity was recently highlighted in two presentations at AGU 2024 (Slad; Shimoda). This is attributable to temperature dependence of permanent magnets used in force-feedback seismic sensors. This small effect can be characterized, and corrected if desired by periodically updating sensitivity metadata, using modern seismic sensors that include an internal temperature reporting capability.

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## Azores infrasound network: Towards a better monitoring of seismo-volcanic activity

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With the installation and certification of the International Monitoring System (IMS) station IS42 in 2011, the Azores archipelago became an infrasound sentinel of the North Atlantic Ocean. After more than a decade of detecting global infrasound activity including microbaroms, Atlantic storms, man-made activities, bolides, earthquakes and far-field volcanic eruptions, a second infrasound array was installed in the Azores to monitor local seismo-volcanic activity. On March 19th, 2022, a volcanic unrest on São Jorge Island triggered the deployment in two weeks of a four-element low-cost portable infrasound array (SJ1), in collaboration with the University of Florence. The results from this experience confirmed the need to improve the infrasound coverage of the Azores, towards a better monitoring of local and regional seismo-volcanic activity, as planned before. In 2023-24, a six-element low-cost infrasound portable array (TER) was designed and assembled, having been deployed in April 2024 on Terceira Island to monitor a local ongoing seismo-volcanic crisis.
A roadmap to design, assemble and deploy a six-element low-cost infrasound portable array on Faial Island (FAY) already started. We also present a project's rationale to deploy an array in Santa Maria Island with four absolute pressure sensors to cover also São Miguel Island.

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## In Situ Calibration of CTBTO Seismic Monitoring Stations in Indonesia

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) operates five seismic monitoring stations in Indonesia. To ensure the traceability of measurement units for these seismometers, in situ calibration is essential. This study presents a calibration methodology based on the ISO 17025 standard, employing a comparative method where the seismometer to be calibrated is placed side-by-side with a reference seismometer. The reference seismometer, provided by the Indonesian Agency

for Meteorology, Climatology, and Geophysics (BMKG) as a CTBTO partner, has been previously calibrated. Several National Metrology Institutes (NMIs) have adopted this in-situ calibration method. By conducting in situ calibration, the traceability of measurement units to the International System of Units (SI) for instruments installed at the monitoring stations can be guaranteed.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 34 / **P3.1-708**

## From errors to insights: the role of Infrasound Calibration in improving troubleshooting activities and system knowledge

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Calibration activities are one of the minimum requirements for stations of the International Monitoring System (IMS), as specified in the IMS Operational Manuals. The ongoing efforts to maintain and recapitalize the infrasound stations of the IMS network have led to the installation of passive calibration capabilities and well-characterized elements, with a new generation of sensors and Wind Noise Reducing Systems (WNRS). The use of the CalxPy tool developed by the Provisional Technical Secretariat (PTS) allows enhanced detection of deviations from theoretical responses, enabling finer diagnostics and streamlined identification of the sources of such deviations. This work presents a number of examples illustrating the recent progress made through the use of CalxPy, both during field missions and during regular monitoring activities, giving an overview of the practical applications of infrasound station calibration and their impact on data quality.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 35 / **P3.1-711**

## Magnetic field monitoring systems compared to systems based on seismic and infrasound for monitoring active volcanoes

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In this work, a monitoring system has been developed to measure the variations in the magnetic field produced at the Chiles volcano, located in Ecuador on the northern border with Colombia. Additionally, an array composed of 12 one-component sensors arranged in various geometric configurations has been implemented in order to detect seismic and infrasound signals. The system refers to a

compact and highly reliable prototype used in volcanic monitoring applications. It is composed of magneto-metric sensors and makes use of long-range wireless transmission technology known as LoRa (Long Range). Furthermore, it has a controller developed on an Arduino platform that has two serial communication interfaces. Lastly, as a complement to this magneto-metric system, a seismic station is used that has an embedded system that is responsible for the acquisition, digitization and continuous storage of seismic and infrasound signals captured by the array of 12 sensors. The data collected from the variables under study, i.e. magnetic field variation and seismic signals, have been subjected to rigorous statistical correlation analysis. As a result of this analysis, we have identified several anomalies in the magnetic field in the geothermal zones of the aforementioned volcano.

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## Advancements in quality assurance for the International Monitoring System and calibration challenges for seismic and infrasound technologies

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The International Monitoring System (IMS) network relies on four technologies: seismic, infrasound, hydroacoustic and radionuclide. The draft IMS Operational Manuals for waveform technologies outline the requirements for establishing, maintaining and verifying the performance of IMS stations. Since 2011, the Provisional Technical Secretariat (PTS) has collaborated with the global community to establish a robust quality assurance framework for IMS measurements, with focus on infrasound technology: significant progress in setting standards and refining calibration methods was achieved. Recent PTS activities focused on seismic technology. The IMS seismic stations are required to perform regular calibration, maintaining a maximum deviation of five percent in amplitude and five degrees in phase over the frequency range relevant for detecting nuclear explosions. This necessitates precise calibration processes to ensure consistent measurement standards between IMS facilities. Currently, seismic stations undergo yearly electrical calibrations. However, this approach is not traceable and may not capture long term trends influenced by multiple factors, including environmental components. Alternative or complementary methods, such as calibration by comparison, might provide additional insights and support measurement accuracy for seismic technology. This work reviews recent advancements in seismic sensor quality assurance and invites experts to collaborate on developing alternative calibration methods to improve traceability and measurement reliability.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 37 / **P3.1-738**

# The Algerian Network for Infrasound (ANIs)

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This poster presents the Algerian Network for Infrasound (ANIs), a pioneering project aimed at establishing a comprehensive network of low-cost infrasound devices across Algeria. In its initial phase, the project involves the deployment of four infrasound sensors in the northern part of the country, with two devices operational since June 2022. Preliminary data from these two operational devices have revealed a variety of natural and anthropogenic infrasound sources. Detected events include lightning strikes, strong earthquakes, quarry explosions, cyclones and volcanic activity. Notably, during this period, two significant fireballs were detected and analyzed using data from local seismic and infrasound networks, as well as from the International Monitoring System (IMS) network. The first fireball event occurred in the Dellys region on 24 November 2022 and is further detailed in the oral communication presented at SNT 2025 by Bouyahiaoui et al. The second event, observed in northern Algeria on 7 May 2023, is discussed in a manuscript submitted for publication recently. These findings underscore the potential of ANIs in enhancing the detection and study of infrasound phenomena across diverse contexts.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 38 / **P3.1-742**

# Calibration and Quality Control in the Design and Manufacture of Seismic Instrumentation

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Broadband seismometry is a foundational instrumentation technology enabling measurements of seismicity for test ban treaty verification. Seismic monitoring networks typically comprise many stations distributed geographically on the Earth's surface or seafloor. Seismic station data used for test ban treaty monitoring purposes must be trustworthy, meaningful and reliable. The seismic instruments employed must be sufficiently and confirmably accurate, precise and dependable. Calibration and verification of seismic instrumentation in the manufacturing process are key elements in establishing accuracy with sufficient precision. We discuss several related considerations that arise when designing and manufacturing the seismometers and digitizers that are at the heart of seismic stations: The distinct nature and value of accuracy and precision of seismic instrumentation. How accurate and precise is good enough, or too much? Accuracy vs precision in manufacturing. Alternative calibration methodologies and approaches in manufacturing. How uncertainties arise

and their impact on accuracy and precision. Traceability to SI standards in factory certification processes. Metrics to consider: sensitivity, transfer function, timing, calibrator features, alignment, etc. Lastly, we discuss why instrument accuracy and precision are necessary but not sufficient, and some calibration techniques users may employ in the lab or in the field.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 39 / **P3.1-754**

## A New Self-Calibrating Infrasound Sensor Design

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We will present the results of testing of a new self-calibrating infrasound sensor design, developed by Hyperion. This design integrates a sound source and system controller logic into the body of a Hyperion infrasound sensor. Both analog and digital versions of this design were constructed and tested. The calibrator produces a sinusoidal pressure signal with amplitude and frequency specified by the user into the back-volume of the infrasound sensor. The calibration controller corrects for static pressure and temperature effects on the pressure source, and the system can be operated fully remotely. Results of testing of this system will be presented along with a discussion of possible improvements of this design, including improvements in methodology which would make this system more directly traceable in a metrological sense.

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## Applicability of Quantum Technologies for the Enhancement of the CTBTO Verification Activities

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Currently, the world is undergoing the second quantum revolution. While the first revolution resulted in a wide range of transformative technologies, including nuclear weapons, developments

emerging from the second revolution, including a range of promising quantum technologies, seem to be enhancing the monitoring capabilities of the CTBTO. This study explores the potential of quantum sensing, computation and cryptography to enhance the IMS, addressing critical issues of nuclear test detection.
Quantum sensors promise unprecedented sensitivity in detecting seismic, hydroacoustic and infrasonic anomalies. These capabilities can significantly improve the resolution and accuracy of monitoring subterranean nuclear tests. Similarly, quantum gravimetry and magnetometry enable precise identification of underground voids or disturbances caused by nuclear activities, even in complex geological environments. Moreover, quantum cryptographic methods can ensure the security of sensitive monitoring data transmissions, reducing risks of interception or manipulation. Although quantum technologies remain in their developmental stages, they represent a highly promising scientific and technological area. Their integration with other innovations, such as AI, drones, etc., has the potential to provide the CTBTO with highly effective monitoring tools, both for non-proliferation and nuclear control and natural disaster warning systems and risk reduction.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 41 / **P3.1-800**

## Results from an Ultra Broad band Borehole seismometer with flat response over five decades of frequency is presented

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The design details of the Ultra Broad Band (UBB) borehole feedback seismometer are presented including stable Hole-lock camping mechanism. The complete sensor stack weighs less than 20 Kg with a diameter of 89 mm.
The instrument has no mechanical resonances below 400 Hz. We achieved the bandwidth extension to high frequencies with improvements of the mechanical design, i.e. the arrangement of the pivots and the geometry of the spring.

Cost effective Ultra Broad Band Borehole seismometer results are presented. We show test results from a system installed in 200 meter deep Borehole comparing results to a surface Broad-Band sensor.

The Broad band sensor system High frequency noise performance cuts the NLNM close to 20 Hz. The system is capable of detecting Eart tides.

Unlike “Tilted Galperin” topology the “Classic Orthogonal” topology used in this system provide borehole tilt information from the Horizontal components. Furthermore, the advantages of a “Classic Orthogonal” Broad band sensor system is presented with detailed results.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 42 / **P3.1-842**

# Identification of Seismic Noise Sources and Site Characterization of the Ina-TEWS Permanent Seismic Network, Indonesia

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A seismic network's primary objective is to provide high-quality data for monitoring earthquakes, analyzing their sources and studying the structure of the Earth. The good quality of seismic data is obviously important but can only be achieved if many different factors are considered. The quality assessment was verified by using the seismic waveforms from a total of 537 permanent broadband stations in the Ina-TEWS Network in Indonesia. The quantification of seismic noise quality is based on the evaluation of daily noise levels and the characterization of the seismic sites. Power spectral density (PSD) and horizontal to vertical ratio (HVSR) of individual seismograph forms the basis of a set of tools used to evaluate an instruments performance as well as the characterization of the seismic stations. Some seismic noise sources were found mainly attributed to cultural noise, instrument noise and the instrument installation. Furthermore, this study also provides discussions about the development trend of data quality evaluation based on the actual broadband observation conditions in Indonesia.

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**P3.1 Seismic, Hydroacoustic and Infrasound Technologies and Applications** - Board: 43 / **P3.1-887**

# Establishing a service for calibration of low frequency transfer standard microphones in the frequency range 10 mHz to 250 Hz

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In the EMPIR Infra-AUV project, HBK-DPLA extended the frequency range of the reciprocity calibration technique to achieve reliable primary calibrations to frequencies below 40 mHz. It was also demonstrated that secondary calibration based on HBK's commercially available low frequency calibration system can be made of suitable microphone types down to similar frequencies. After the project, development has continued and now reciprocity calibrations and secondary calibrations can be made with low uncertainty down to 10 mHz. Also, the influence of static pressure on the sensitivity of the microphones in the frequency range has been determined, so it is possible to use the microphones as references at all realistic altitudes. In this presentation, the steps in the development, the challenges encountered on the way and verification of the methods are briefly presented and discussed. Which types of microphones that are suitable for the steps in the traceability chain

from the primary calibration to the field measurement station, and how they are characterized with respect to sensitivity to environmental conditions, are also discussed. As a result of the effort, it has been possible to establish a calibration service for transfer standards that can be used in laboratories as well as in the field.

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**Online e-Poster Session 2** - Board: 0 / **P3.2-074**

## An alternative silver-exchanged zeolite for noble gas collection and separation

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Noble gas monitoring systems are used in the International Monitoring System (IMS) for the verification of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). They monitor the atmosphere for traces of radioxenon released by clandestine nuclear weapon tests. Radioargon is used as a complementary tracer during on-site inspections to look for underground tests. Efficient collection and purification of noble gases in porous adsorbents is essential for the detection capability of these systems. In the last decade, silver-exchanged zeolites (Ag-zeolites) have been investigated for these applications. Currently, two Ag-zeolites (Ag-ETS-10 and Ag-ZSM-5) are used in the new generation radioxenon monitoring systems in part of the collection and separation process. Ag-ETS-10 has been investigated for argon collection and separation for OSI. Each Ag-zeolite has specific noble gas adsorption properties, which are driven by the presence of silver. Other Ag-zeolites might provide further developments for radioxenon and radioargon measurements. In this work, we investigate different modified mineral chabazites, exchanged with silver, for their application in CTBT verification, by characterizing their xenon and argon collection and separation properties. Initial measurements on one sample showed a close match, to the current Ag-zeolites, used in the IMS, for Xe collection. Further results of this investigation will be discussed.

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**P3.2 Radionuclide Technologies and Applications** - Board: 1 / **P3.2-136**

## INVAP STAX monitor installation at La Reina RR (Santiago, Chile)

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A newly commissioned STAX series monitor, developed by INVAP, has successfully completed factory acceptance tests and demonstrated reliable data transmission in accordance with STAX project requirements. This monitor is scheduled for installation at the La Reina RECH-1 Research Reactor facility in Santiago, Chile, during the first half of 2025. This unit represents an upgraded version of the monitor currently operating continuously since November 2021 at the Radioisotope Production Facility in Ezeiza, Buenos Aires, Argentina, including improvements on software user interface and equipment accessibility and maintainability. The system has undergone rigorous calibration and finetuning of its electronic setup and detection system, which features an ORTEC Coaxial P-type HPGe Gamma-Ray Detector with 10% efficiency, an ICS Integrated Cryocooling System, and an Ultra-High Count-Rate Preamplifier. These optimizations enhance measurement performance, allowing for precise monitoring of high-activity concentration emissions even in low-dilution conditions.
This presentation will cover the technical characteristics, performance metrics, and preliminary results achieved with this advanced monitoring system.

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**P3.2 Radionuclide Technologies and Applications** - Board: 2 / **P3.2-173**

# Array Solutions for Radioxenon Monitoring

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The SAUNA QUBE, developed by the Swedish Defence Research Agency and manufactured by Scienta Envinet, represents a major advancement in atmospheric radioxenon monitoring. It offers high performance at significantly lower costs than its predecessors, allowing the creation of dense monitoring arrays that improve detection probability, data availability, and source localization precision. To match this hardware development, Scienta Envinet is devoting significant energy to developing analysis tools for efficient use of array data, with a focus on atmospheric transport modelling and robust emission source tracking algorithms that can be used as part of the routine operation. This talk will give an overview of how radioxenon monitoring arrays are constructed and managed in practice, including how data is handled in the central monitoring software Network Monitoring Centre, and provide example results from the source tracking algorithm applied to real world cases.

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**P3.2 Radionuclide Technologies and Applications** - Board: 3 / **P3.2-176**

# Acoustic Agglomeration of Aerosol Particles in Benefit of RASA 2.0

**Authors:** Michael E. Swanwick[1]; Lena Dubitsky[1]; Kenneth McEnaney[1]; Jessica M. Elliott[1]; Clive L. Devoy[1]; Jed C. Wilbur[1]

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Existing radionuclide aerosol collection systems within the CTBT's International Monitoring System operate near the noise floor of the gamma spectrometer measurement. Increasing the flow rate of radionuclide aerosol systems while meeting the CTBT's specified collection efficiencies will increase particle collection and, potentially, decrease sample interval. Creare developed a detailed model of an agglomeration system designed for the particularly hard-to-collect small particles and low particle densities of interest. Our design uses an array of acoustic horns and drivers in the confined flow area to drive the agglomeration of small particles with larger particles or seed aerosols, making them easier to collect. Our agglomeration model includes effects from orthokinetic, acoustic wake, particle collision efficiency, population balance, Brownian motion, and van der Waals forces to predict the statistical likelihood of any particle sticking to any other particle in the turbulent flow stream with high sound pressure. Our statistical and finite element analysis modeling results show the need for fine seed particles to enhance agglomeration efficiency by increasing relative particle density. We also detailed the effect of changing the residence time of the particles in the flow field, the effect of frequency, and sound pressure level.

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# Application of indirect quantification of Xe-133m to calibration of HPGe Detector

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The INL Noble Gas Laboratory provides intercomparison samples for the noble gas analysis laboratories as part of the International Monitoring System. Xe-133m is one of the four relevant radionuclides in nuclear explosion monitoring. Without commercially available Xe-133m calibration standards laboratories must create and improve calibration methods. Improvements in calibration methods at the INL NGL benefit the CTBTO through better certified values for Xe-133m intercomparison samples. Calibration of high purity germanium detectors for Xe-133m quantification is complicated by the coexistence of Xe-133 in samples under analysis. Xe-133 is typically produced in larger quantities, has higher gamma emission probabilities, and its gammas are detected more efficiently than Xe-133m. Xe-133m activity of samples can be indirectly inferred through the 133:133m activity ratio of a batch of material, and the Xe-133 counts in the assay of a small aliquot of the same material. This indirect quantification method can be leveraged to perform detector calibrations for quantification of Xe-133m. Calibrations can be performed by inferring the Xe-133m to certify the sample, and direct counting to determine detector efficiency. A comparison of method results will be shown.

Funding provided for this work comes from INL program development funds and from NA-243 for travel related expense.

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**P3.2 Radionuclide Technologies and Applications** - Board: 4 / **P3.2-237**

## Uncertainties in the SAUNA measurements - calibration revisited

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The calibration procedure used for SAUNA-type noble gas systems has been revisited. Input data to the calibration procedure was resampled using a bootstrapping method, this showed that uncertainties in detection efficiencies and interference correction ratios estimated by earlier procedures were too large. For this reason, the curve fitting method and its uncertainty evaluation was revised. Improvements to the procedures, in terms of more robust curve fitting and enhanced uncertainty estimates, are presented. Calibration parameters, e.g. detection efficiencies, resulting from the updated procedure are compared to earlier data. In addition, the calibration procedure leads to covariance between the resulting calibration parameters. The impact of these covariances on the uncertainties on Xe-isotopic ratios were studied.

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**P3.2 Radionuclide Technologies and Applications** - Board: 5 / **P3.2-263**

## Global and automatic analysis of radioxenons in beta-gamma spectrum.

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In the scope of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), the detection of radioactive xenon by the stations of the International Monitoring System (IMS) is a crucial challenge for the detection and the qualification of nuclear tests. This task is made difficult because of the low activity of these elements present in trace amounts in the atmosphere.
The laboratory is therefore testing a new analysis method for the global beta-gamma spectrum, which allows for the use of all information present in the spectrum. This method has already been

tested on a detector in development with a low resolution for photon and a high resolution for electrons. It has proven capable of reducing detection limits for radioxenons of interest. This method is now being tested on the model of one of the low resolution detectors.
The accuracy and precision of the algorithm are evaluated for the quantification of the activities of radioxenons of interest. In addition, characteristic limits (decision thresholds and detection limits) are evaluated and compared to those given by the reference method currently used on the IMS. In addition, a new method for calculating the uncertainty of the radioxenon activities and for an experimental spectrum is presented.

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## SAUNA III: Lessons Learned

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Since its certification by CTBTO into the IMS network, a total of eight SAUNA III systems and one SAUNA III laboratory have been installed in the field and several additional upgrades are on the way. Four of the installed systems are in the IMS network and the others are independent customers in Europe and the Middle East. On this poster we report on the lessons learned from the first years of operation and on how these experiences are taken into account to improve the quality, reliability and long-term sustainability of our systems. Experiences have been made in the technical aspect, such as extending MTBF for pumps and valves, improving serviceability and adjusting preventive maintenance intervals to keep the systems in perfect condition. The goal of all improvements is to make SAUNA III the most competent and reliable system in the Noble Gas detection arena, but also to build the best service organization to meet customers high demands.

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## Radiological Impact Analysis of Hypothetical Space Reactor Re-Entry Using HotSpot Code

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The development of space reactors represents a crucial advancement in exploration, providing sustainable energy for extended missions and emergency scenarios. This study focuses on the radiological impacts of a hypothetical space reactor accident during atmospheric re-entry at an altitude of 70 km, where aerodynamic and thermal stresses increase the risk of structural disintegration and radionuclide release. Utilizing the HotSpot code for radionuclide dispersion simulations, the research predicts dose distributions up to a distance of 200 km. The HotSpot simulations indicate that the Total Effective Dose Equivalent (TEDE) at a distance of 0.03 km was 130 Sv on the first day, rising to 710 Sv after 55 years, reflecting the long term environmental radiation exposure. Organ-specific analysis using HotSpot showed that the liver absorbed 130 Sv on the first day, with a cumulative dose of 1300 Sv over 55 years. Persistent contamination was observed up to 80 km, where TEDE values were still measurable at 0.036 Sv after 55 years. These results emphasize the need to mitigate both immediate and long term radiological risks, supporting enhanced safety protocols and environmental monitoring for space reactor operations.

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**P3.2 Radionuclide Technologies and Applications** - Board: 8 / **P3.2-404**

## First results of world's first Snow White air sampler equipped with LaBr3 detector

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Many countries around the world use high volume samplers to sample air for radioactive particulate measurements. For many years, the Dutch National Institute for Public Health and the Environment (RIVM) performs the sampling and measurements in the Netherlands for environmental monitoring purposes. Since 2011 a Snow White air sampler from manufacturer Senya Oy is used, which is the same air sampler that is used at the particulate stations in the International Monitoring System (IMS) of CTBTO. In January 2025, a new Snow White is installed at a new location to replace the old one. The new Snow White is equipped with a $LaBr_3$ spectroscopic detector. This detector continuously measures the activity concentration on the filter during the sampling. With this system, an increase in activity concentration can be detected in real time. According to Senya Oy, this is the first Snow White in the world with such a detector. On this poster, the first results of the new system and the new location are presented.

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## A Continuous and Automatic Argon-37 Monitoring Station

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Various human-made phenomena such as medical isotope facilities and power plants have complicated the understanding of radioxenon measurements. Argon-37 could be added to increase confidence in observations. However, the atmospheric background of argon-37 is not as well understood as the radioxenons. Pacific Northwest National Laboratory has developed a new continuous and automatic benchtop capability designed to measure atmospheric argon-37 background levels. This capability has been operational for several campaigns to begin understanding natural variations in these levels. System operations, first findings and detection limits will be discussed as well as the next steps to increase these limits and effective system up-time

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## Long Term Radioxenon Efficiency Calibration Study of Beta-Gamma Detectors

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This study investigates the long term variations in radioxenon efficiency calibrations by conducting nearly monthly calibration experiments over an extended period on a single system. Historically, radioxenon detection systems are calibrated infrequently, often only once or very rarely, raising concerns about the long term accuracy and reliability of the detectors. Accurate and consistent calibrations is vital for reliable data interpretation. In this research, multiple efficiency calibrations were performed to track changes in detector performance and to assess whether more frequent calibrations are necessary. The primary objective of the study was to discern any trends or anomalies in calibration efficiency over time, which could impact the precision of radioxenon measurements. The results of the long term study will be presented.

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## Increasing the resolution of a scintillation detection cell using a diffuse reflective coating and assessment of the retention of performance characteristics during aging of a protective coating made of poly-chloro-para-xylylene

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Modern systems for detecting radioactive noble gas isotopes require high sensitivity, reliability and durability. One of the critical challenges is minimizing the memory effect, which manifests itself as residual activity on the surface of the detectors. Previously, VNIIA developed a barrier coating technology for scintillation cells using poly-chloro-para-xylylene, known for its high gas barrier properties, chemical resistance and durability. Applying a 4–5 μm coating reduced the memory effect by 78%, while a 7–8 μm coating achieved an 89% reduction but compromised resolution and efficiency of the detector.

This study aimed to enhance the efficiency of detectors by using a diffuse reflective layer based on barium sulfate. This material, with high reflectivity and resistance to environmental impacts, improved scintillation signal registration efficiency by 50%. Aging stability was also examined, with results showing that after 2.5 years of natural aging, detector efficiency remained at 99% of its original level. Accelerated aging tests indicated a 5–7% decrease in efficiency over ten years.

The findings demonstrate the effectiveness of the applied solutions, including barium sulfate and poly-chloro-para-xylylene barrier coatings, ensuring reliable, long-term performance in radiation monitoring systems. These results confirm the potential for sustained operational reliability under various environmental conditions.

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# Development of a background model for coincidence gamma-ray spectrometry measurements in radionuclide monitoring

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In the Comprehensive Nuclear-Test-Ban Treaty (CTBT), radionuclide monitoring is a key to provide evidence of an explosion being nuclear in nature. In this respect, the gamma-ray coincidence spectrometry has emerged as a powerful technique to suppress background from naturally occurring radioactivity while maintaining good efficiency for coincident gamma-ray emitters of interest. Although this technique can be employed with the state-of-the-art high-resolution High Purity Germanium (HPGe) detectors to improve the sensitivity to radionuclides relevant for CTBT verification, the proper estimation of the background is essential for optimizing and designing a coincidence instrument.

For this purpose, it has been found essential to make use of Monte Carlo simulation software. Currently, a background model is being developed using Geant4. The background consists of three components to be used for comparison with experimental data obtained with a single-crystal HPGe detector from 1) an unexposed particulate filter for the collection of airborne radionuclides, from 2) an exposed filter, and in addition 3) the background measured from the detector setup and lab

environment without any filter. The obtained background model is presented and its aimed use for evaluation of candidate coincidence detector designs is discussed.

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**P3.2 Radionuclide Technologies and Applications** - Board: 14 / **P3.2-654**

## Research and selection of new sorption materials for the sample processing device of the MIKS monitoring system of xenon isotopes

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This work is devoted to the study of sorption materials for use in the sample processing device of the MIKS monitoring system of xenon isotopes. The aim of the work was to select new materials with improved sorption characteristics with respect to xenon to ensure stable xenon extraction and reduce the minimum detectable concentration (MDC) for the Xe-133 isotope. To determine the sorption properties of materials with respect to xenon, the preparative gas chromatography method was used. The following zeolites were selected as materials: CaA (5A), PSA/VPSA (13XHP), NaX (13X), LiLSX, ZSM-5, zeolites Ag-ZSM-5 and Ag400 modified with silver nanoparticles, as well as coconut and activated carbon from various manufacturers. The study is carried out on a setup for examining the sorption and separation characteristics of sorbents at various temperatures and pressures. As a result of the work, dynamic adsorption curves (Breakthroug curves) were obtained and the most optimal materials for the final traps of the MIKS were selected.

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**P3.2 Radionuclide Technologies and Applications** - Board: 15 / **P3.2-662**

## Ultra Sensitive Measurements of Airbourne Nuclear Debris

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The Comprehensive Nuclear Test-Ban Treaty (CTBT) International Monitoring System (IMS) is designed to provide a network of 80 Radionuclide detection systems, strategically positioned around the globe to detect particulate radionuclide emissions from nuclear explosions. This paper describes progress on the implementation of ultra-sensitive monitoring systems to the IMS, including the incorporation of gamma coincidence measurements into routine operations, an efficient and automated data collection/processing chain, and analysis methodologies to maximise the value of the

data collected. The importance of these advances, which include significantly improved detection limits, reliability and redundancy of the Treaty measurement, and the potential for an improved (shortened) collection/measurement cycle, are also discussed.

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## Inter-Comparison of FirstLook Detector Performance and Anomalies for State of Health Monitoring in Particulate Radionuclide Monitoring Systems

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Cadmium Zinc Telluride (CZT) based FirstLook detector systems can provide a near-real time look at the collection of aerosolized radionuclides on the filter media in particulate collecting systems. In cases where high levels or radionuclides are present in air masses, FirstLook detectors could provide station operators the ability to tune the collection of the system to prevent contamination of the system. To distinguish such high-level events from normal fluctuations in the levels of naturally occurring radionuclides, the performance of the FirstLook detector under normal collection settings must be well understood. This study will look at the data collected from several FirstLook detectors installed in both RASA and Manual radioaerosol collection systems. Comparing the FirstLook data across several systems, as well as comparing to the HPGe measurements for filters, will set the groundwork for understanding expected background signals and potential anomalous signatures associated with the systems' state of health.

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**P3.2 Radionuclide Technologies and Applications** - Board: 17 / **P3.2-668**

## Initial Operational and Processing Experience for Data from the First Commercial Unit of the Xenon International

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The first commercially available unit of the Xenon International system was installed at the General Dynamics Mission Systems' Engineering Test Bed (Chantilly, Virginia, USA) in May of 2024. In preparation for deployment into the IMS, General Dynamics has operated the system in the same manner as a certified system and has been working in conjunction with the Provisional Technical Secretariat to provide spectral and state of health data from this Test Bed system. Since the installation, General Dynamics has observed several low-level (≤1 mBq/m3) detections. This work will cover the initial experiences in operations, maintenance, and data processing of the Xenon International system. In addition, a comparison of the xenon analyses provided by different tools for the first year of spectral data and the system's first spike samples will be presented.

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**P3.2 Radionuclide Technologies and Applications** - Board: 18 / **P3.2-688**

## Big Xe sample technology

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Usually, a volume of IMS Xe sample is not exceeding a few cc of pure Xe and volume of OSI sample is significant less. Proposed technology increased Xe volume for more than 100 times and provide high sensitivity spectrometric measurement (MDC for Xe133, Xe135, Xe133m and Xe135 always during the measurement were less than 10-5 Bq/m3). MDC for 4 Xe are by several orders less than MDC of existing IMS Xe Systems. The presentation shows a principal of the big sample technology including preparation of Xe-Kr concentrate, sample purification process, spectrometric measurement and familiar with obtaining results. This technology could significantly increase the performance of NG method and significantly improve treaty verification regime: extension IMS station under request, Xe background study, temporary replacement of IMS equipment due to the technical problems with XE equipment by request and etc.

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**P3.2 Radionuclide Technologies and Applications** - Board: 45 / **P3.2-693**

## High-precision stable xenon isotope ratio measurements of atmospheric samples

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IMS nuclear explosion monitoring systems rely primarily on the radioxenon to detect illicit nuclear events. However, these systems require prompt event detection since the main isotopes of interest (<sup>131m</sup>Xe, <sup>133+133m</sup>Xe and <sup>135</sup>Xe) have half-lives between 11.9 days and 9.14 hours. Here, we present a complimentary tool for detecting fission events utilizing high-precision stable xenon (<sup>131</sup>Xe, <sup>132</sup>Xe, <sup>134</sup>Xe and <sup>136</sup>Xe) isotope measurements that can be used as a long-lived, persistent signature for detection. This talk will focus on the development of a measurement methodology, employing a Thermo 253 Ultra dual-inlet dynamic mass spectrometer, that can achieve 10 permeg measurement precision (where permeg is the relative difference, in parts per million, of the isotope ratio of an unknown compared to a reference standard). In addition, we will discuss practical considerations for the collection of samples for these measurements as well as sample purification. We will also present an initial dataset of atmospheric background measurements conducted in northern New Mexico, United States.

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**Online e-Poster Session 2** - Board: 0 / **P3.2-724**

## Xenon International's Quality Control Source for Gain Performance Monitoring

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Xenon International has recently tested a new quality control (QC) source for the nuclear detectors which uses an acrylic housing for a $^{137}$Cs source. The original source holder used in acceptance testing was $^{137}$Cs housed in a stainless-steel pellet. The high Z of the stainless steel attenuated low energy X-rays. The new QC source allows for the lower energy (~30 keV) emissions from $^{137}$Cs to be observed on the NaI detector. The Pacific Northwest National Laboratory (PNNL) has leveraged this new source to both monitor the gain and performance of the nuclear detectors. The gain of the nuclear detector uses the $^{137}$Cs 662-keV emission peak for both the gamma and beta detector. This work focuses on the rotated frame of reference method to monitor the beta detector gain. Over several months, targeted testing was conducted to assess metrics (count rate, dead time, resolutions) derived from the QC measurements. This works describes the testing, measurements and algorithms used for gain and performance monitoring with a QC source.

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## Potential Improvements for a Radioxenon Laboratory Measurement System Operation

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The measurement of low-levels of radioxenon is an important part of the International Monitoring System (IMS) operated by the Comprehensive Nuclear-Test-Ban Treaty Organization Preparatory Commission (CTBTO PrepCom). These stations are continually measuring the radioxenon in air samples to monitor for nuclear explosions. The IMS also includes laboratories capable of measuring radioxenon archive samples from the stations around the world. One of these noble gas laboratories is operated by the United States, USL16-NGL. In recent years, work has been performed to improve the sample throughput and sensitivity of these laboratory systems. In this presentation, we detail a new system capable of processing multiple samples automatically and measuring four samples at a time. We will also discuss methods being used to improve the flexibility for number of samples and xenon sample volume, while also allowing for replicate measurements for improved accuracy. Additionally, we will show work being done to look at detector resolution improvements capable of improved 131mXe and 133mXe measurement for enhanced radioxenon source discrimination.

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**P3.2 Radionuclide Technologies and Applications** - Board: 21 / **P3.2-807**

# Calibrating a beta-gamma coincidence detector system for assay of Xe-127

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Xenon-127 is a neutron-deficient radionuclide produced from neutron activation rather than fission, for example via radiative capture on stable xenon-126. It is not an isotope actively monitored as a signature of a nuclear test; however, its longer half-life (36 d), measurable nuclear decay emissions and lack of environmental background signal make it an ideal tracer radionuclide for radioxenon-related field experiments. Physics Experiment-1 (PE-1) involved the use of Xe-127 as a tracer for fission product radioxenon and was monitored in the field using a SAUNA QB system. The fielded detectors had not been previously calibrated for this radionuclide and no industry method had been published previously. To calibrate the SAUNA system for measurement of the tracer, a series of laboratory measurements were conducted on similar detector setups using isotopically pure gas. A calibration scheme was devised and compared to detector models and singles gamma spectrometry measurements, demonstrating very good agreement. Several key trends were identified from the calibration measurements, showing an efficiency dependence on the xenon gas concentration for some coincidence regions of interest in the energy matrix. An overview of the calibration work and findings are detailed.

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## Development of a multi-detector system for identification of low-activity CTBT-relevant radionuclides

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The International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) includes 80 radionuclide stations performing continuous radionuclide particulate monitoring, supported by a network of 16 radionuclide laboratories which undertake verification and reanalysis of samples. The current analysis technique employed across the IMS uses high-resolution gamma spectroscopy to identify and quantify which radionuclides are present. Ongoing efforts to increase the sensitivity of measurements and reduce detection limits have seen the development of more advanced techniques. Multi-detector systems can be utilised to vastly reduce the signal-to-noise ratio of measurements by only considering counts that have a coincident hit in another detector. When applied to low-activity samples this technique can be used to identify and quantify radionuclides that would otherwise not be possible to detect with conventional single detector systems, in addition to greatly reducing the minimum detectable activity. This poster presents work being conducted at the UK's radionuclide laboratory, GBL15, on a multi-detector system for the application of identifying low-activity CTBT-relevant radionuclides.

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**P3.2 Radionuclide Technologies and Applications** - Board: 23 / **P3.2-865**

## Results of the Automated and Interactive Radionuclide Reports comparison between International Data Centre (IDC) and baseline reports from National Data Centres (NDCs)

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National Data Centres (NDCs) participated in 2024 Experiment by performing Automated and Interactive analysis of Radionuclide Spectral Data and produced both the Automated Radionuclide Reports (ARR) and the Reviewed Radionuclide Reports (RRR) for a selection of particulate and noble gas sample spectra. The NDC reports are used to produce the baseline reports for comparison

with the IDC products for three quality parameters: (1) number of peaks detected where peak detection and identification apply only to particulate systems, (2) number of correctly identified relevant radionuclides, and (3) activity concentration of the quantified radionuclides. The metrics used for nuclide quantification accuracy comparison are percent difference (%D) between the IDC and the NDC activity concentration and zeta (ζ) score in line with ISO 13528:2022(E).
This poster will demonstrate the methodology used for the quality assessment of the IDC radionuclide products and summarize the main findings and lessons learned.

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**P3.2 Radionuclide Technologies and Applications** - Board: 24 / **P3.2-873**

## Role of the radionuclide laboratories in the IMS network

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The International Monitoring System (IMS) network of radionuclide monitoring stations is supported by the PTS certified radionuclide laboratories through the analysis of particulate and noble gas samples from these stations.

The purposes of the laboratory analysis are to corroborate the results of the routine analysis of a sample from an IMS station, to provide more accurate and precise measurements, to clarify the presence or absence of fission and/or activation products in the case of a suspect or irregular analytical result from a particular station and in the case of failure in the measurement capability at a radionuclide station, to temporarily analyse the sample from that station.

The performance assessment of certified radionuclide laboratories is done through their participation in the Network QC and Level 5 programme, Proficiency test exercises and Surveillance assessments.

This paper will emphasize the important role of radionuclide laboratories in the supporting IMS network and PTS verification programme. For that purpose, the outcome of the laboratory performance assessments will be presented, assuring their continuous compliance with the certification and operational requirements.

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**P3.2 Radionuclide Technologies and Applications** - Board: 25 / **P3.2-880**

## RASA 2.0: A Next Generation Aerosol Sampler/Analyzer Update

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Lessons learned from more than 20+ years of aerosol sampling have better informed the International Monitoring System community of heightened needs for an updated aerosol monitoring capability. Increased efficiency contributing to delivering lower minimum detectable concentrations, system resilience, system agility and better timely access to data are just some of the heightened performance parameters being explored. This work will be an update and integrated look at the various components of a next generation aerosol monitoring system. In utilizing state of the art technology in aerosol sampling with Electrostatic Precipitation (ESP), integrated sample handling, as well as dual-gamma radiation detectors better performance can be obtained. Current modeling, testing and development shows a clear benefit in operational performance and a greatly enhanced next generation aerosol monitoring system.

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## Research on Intelligent Sampling Process for Atmospheric Radioactive Xenon Based on Online Mass Spectrometry

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In response to the demand for high-sensitivity monitoring atmospheric radioactive xenon isotopes, this study investigates an intelligent dynamic sampling method based on online mass spectrometry technology. Traditional atmospheric xenon sampling processes rely on time-fixed control modes and stable xenon measurement techniques using thermal conductivity detectors, which suffer from issues such as process response lag and fluctuations in sample purity. This research integrates an online mass spectrometer with a micro gas sampling device, achieving a comprehensive online monitoring system capable of semi-quantitative real time detection from ppb-level atmospheric concentrations to high-purity xenon. The core of the intelligent sampling technology lies in establishing a collaborative control system between the online mass spectrometer and a programmable logic controller (PLC). By using the xenon concentration signals fed back from the online mass spectrometer, the PLC can dynamically adjust the adsorption and desorption parameters, replacing the traditional fixed-timing control logic and enabling real time optimization of process parameters. The application of this intelligent dynamic sampling technology is expected to significantly enhance the accuracy and timeliness of atmospheric radioactive xenon monitoring, providing a solid technical foundation for the intelligent and adaptive development of atmospheric radioactive xenon sampling.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 1 / **P3.3-007**

## The open source software GPRmax for simulating GPR scenarios relevant to OSI missions

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Ground Penetrating Radar (GPR) is a crucial geophysical technique used by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) during On-Site Inspections (OSI) to detect and investigate subsurface anomalies potentially associated with underground nuclear tests. This paper explores the application of the open source software "GPRmax" to simulate GPR scenarios relevant to OSI missions. GPRmax, which employs the Finite-Difference Time-Domain (FDTD) method for the resolution of Maxwell's equations, enables realistic modeling of electromagnetic wave propagation through various geological environments. This study focuses on simulating typical OSI scenarios, including the detection of underground cavities, tunnels, and other subsurface features that may indicate nuclear testing activities. The flexibility of GPRmax allows the customization of antenna frequencies, soil properties, and target compositions, which are vital in optimizing GPR system parameters for diverse OSI conditions. Simulations demonstrate GPRmax's capability to model complex subsurface environments accurately and provide critical insights for field operations. Validation against real world data confirms the software's reliability and effectiveness. As an open source tool, GPRmax fosters collaboration, allowing CTBTO researchers and inspectors to enhance and adapt GPR models to meet specific mission requirements. This study underscores GPRmax's value in advancing GPR methodologies for nuclear test monitoring and OSI operations.

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**Online e-Poster Session 2** - Board: 0 / **P3.3-076**

## Further study of the multispectral equipment based on the first OSI equipment list

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In 2021, PTS presented the first comprehensive draft list of equipment for use during OSI, which is another milestone for the further development of the OSI verification regime. Multispectral imaging plays a vital role for the identification of potential OSI related anomalies and observables like abnormal heat sources, surface disturbances of vegetation and soil. In this work, further study of the multispectral equipment based on the first OSI equipment list has been carried out. An airborne OSI multispectral imaging system covering the core specifications of the OSI multispectral equipment has been proposed, with the spectral range from 0.3 to 2.5 μm. Based on the system, a series of field tests to detect the simulated OSI anomalies and artifacts have been carried out. Based on the obtained multispectral image data, an OSI-relevant information extraction model has been established, in the meanwhile, data processing and an information extraction software platform have also been developed, which can be used for further development of OSI multispectral equipment.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 3 / **P3.3-078**

# Application 2-D Radial Electrical Resistivity Imaging Profiles for Delineating Subsurface Explosion Disturbance Pattern around the 18:45 GMT 17 January 2024 Ibadan, Nigeria Explosion

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2-D radial electrical resistivity imaging profiles established around ground zero of the 18:45 GMT January 17, 2024 Ibadan, Nigeria explosion was adopted as an on-site inspection geophysical approach to establish the subsurface explosion disturbance pattern and delineate the lateral and depth extents. The blast was reported to have resulted from poor handling of mining explosives causing loss of life and wreaked havoc, with noticeable destructive influence beyond the 500 m radius. Geophysical data acquisition, carried out hours after military clearance, employed 12 radial profile configuration established at 300 apart. Wenner electrode configuration was deployed at a=5, and increased serially at a multiple of 5 for 5 levels. Acquired data were filtered, inverted and combined to generate 2-D resistivity sections, radial iso-depth resistivity maps, and 3-D subsurface geophysical model. Characteristic very low resistivity zone, which reflects the blast induced subsurface disturbance, fans out from the centre of the analogy (ground zero) in an approximately semi-radial pattern and trends along northwest–southeast, with influence gradually reducing with depth up to 16 m. Numerous stress induced fractures which differ in pattern from the convectional Pan-African Orogeny-induced northeast-southwest lineament were delineated. The detected disturbance pattern suggests 2-D radial electrical resistivity imaging profile technique as a reliable on-site inspection tool for mapping subsurface explosions.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 4 / **P3.3-097**

# Main VNIIA Focus Areas Related to the CTBT Technologies

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The report presents a description and results of ongoing research at VNIIA on the following areas related to CTBT:
- research in the field of a scientific and methodological support and hardware and software for the CTBT on-site inspection activities, provides a comprehensive assessment and analysis of efficiency of controls and data information content published by the International Data Centre (IDC);
- results of the analysis of events which reveal a possible non-compliance with the CTBT on the part of other States Parties, collects the geophysical and radionuclide information based on products of the IDC;
- results in the field of the development of the data analytics system to use in applied research for monitoring CTBT compliance;
- results in the field of the development of a seismic complex for technical support of the on-site inspection of the CTBT using seismic monitoring methods (passive seismological monitoring, resonance seismometry);
- description of approaches to the development of a software and hardware complex for monitoring compliance with the CTBT, allowing for a full cycle of processing seismic and infrasound continuous geophysical information based on modern algorithms for processing digital geophysical information.

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**Online e-Poster Session 2** - Board: 0 / **P3.3-100**

# A comparison study of magnetotelluric and electrical resistivity surveys as continuation period techniques for on-site inspection

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During any on-site inspection programme of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), field geophysics applications used after results from the initial inspection period indicate the need for further investigation. Ground Penetration Radar, resonance seismometry, active seismic survey, electrical resistivity surveys, gravitational and magnetic mapping are the main geophysical methods used. In this study, magnetotelluric and electrical resistivity surveys were compared by conducting electrical resistivity and magnetotelluric surveys over a successful saline water capped borehole that was likened to be a nuclear test hole. Results from both surveys were able to pick the position of the saline water which indicate the ability of both methods to investigate underground nuclear test explosion sites. Besides, the magnetotelluric survey was able to infer deeper conductive zones far beyond the depth of the borehole. This suggest that the magnetotelluric survey investigates greater depths and can identify cavities that might be created by an underground nuclear test explosion.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 7 / **P3.3-334**

## Verification technologies for the zero-yield standard

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The zero-yield standard prohibits explosive experiments involving a supercritical fission chain reaction while permitting subcritical experiments. The latter are still conducted by certain nuclear weapon states today to ensure the performance and safety of their nuclear arsenals. However, there have been growing tensions between these states as they suspect each other of violating the zero-yield standard by conducting supercritical explosive experiments at very low yields. Since the International Monitoring Systems cannot detect very low-yield experiments let alone distinguish a supercritical from a subcritical experiment, there is an urgent need to develop verification technology and protocols that would make it possible to verify the zero-yield standard. This work presents various proofs-of-concept of scientific methods based on gamma spectroscopy to distinguish supercritical and subcritical experiments during an on-site inspection. These methods have been developed and tested via high-fidelity, physics-based computer simulations of very low-yield experiments and gamma detectors, including neutronics, isotopic evolutions and photon transports. Demonstrating and deploying these methods would strengthen the verification regime of the CTBT, decrease suspicions of violations of the zero-yield standard and reinforce adherence to the nuclear test ban.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 8 / **P3.3-386**

## Developing an On-Site Inspection System Using Machine Learning

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Verification of compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) requires highly accurate analysis methods. Based on the fission products analysis, it is proposed to increase inspections efficiency by using machine learning.

As part of research conducted by students from the National Research Nuclear University MEPhI, a system is currently being developed that automates process of data collection and analysis. The main goal is to use machine learning algorithms to analyze gamma- and mass-spectrometry data, allowing for the determination of the time and nature of a nuclear event based on fission-produced isotopes data.

The up-level approach involves integrating machine learning with international data center, enabling real-time analysis of radioactive isotopes and detection of potential violations. The system minimizes the human-factor aspect and accelerates decision-making processes.

The expected outcome is the development of a universal tool that will become an integral part of the global verification system for the CTBT. The study emphasizes the substantial contribution of students from MEPhI to advancement of technologies for global nuclear security and control.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 9 / **P3.3-452**

## Increasing the Accuracy of Detection of Underground Nuclear Explosions During On-Site Inspection Based on Changes in Residual Magnetization

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To improve on-site inspection detection techniques, it is proposed to investigate the area based on changes in the local electromagnetic field of the Earth in the vicinity of the explosion site for residual magnetization.

As part of the research conducted by MEPhI students, approaches aimed at analyzing changes in the electromagnetic characteristics of the environment are being developed. The main idea is to study changes in the geomagnetic field resulting from irreversible deformations and fractures at the site of an underground explosion.

The upgraded approach includes the use of measuring systems that make it possible to record the residual magnetization and current distribution in a disrupted environment. These data are used to evaluate the parameters of the explosive impact, such as the size of destruction zone and changes in electrical conductivity.

The proposed method will increase the reliability of the detection due to a prolonged altered state (medium magnetization up to several months) after the test. The study highlights the contribution of MEPhI students to the development of technologies to improve the accuracy of verification and ensure nuclear safety.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 10 / **P3.3-460**

# On-Site Inspections in Challenging Environments with Reference to Recent Volcanoes

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The phrase "On-Site Inspections (OSIs) in challenging environments" has been extensively used in reference to OSI exercise environments. For example, the OSI build-up exercise 2024 (BUE2024) was held in somewhat mountainous/rugged terrain and the next Integrated Field Exercise (IFE) is anticipated to be held in a tropical rainforest environment. These are just a few among many other OSI challenging environments. This abstract considers possible conduct of an OSI in areas of recent (late Quaternary) caldera volcano, e.g. Menengai caldera, formed on a massive shield in the inner-trough of the Kenya rift valley. The caldera is associated with a high thermal gradient resulting from shallow magmatic intrusion. The caldera floor is overlain and extensively covered by pera-alkaline trachy-phonolites. In addition, thick vegetation and deep gulleys and faults characterize the caldera floor. These trachy-phonolites as well as the surface morphology are likely to impede the conduct of surface geophysical techniques including passive seismic monitoring (PSM). Further, they are likely to severely slow down the conduct of visual observation (VOB), position finding (POS), and both low and high energy resolution analysis (ERA-L and ERA-H) inspection activities. During the forthcoming SnT2025, these limitations on OSI activities and techniques will be discussed in more details.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 12 / **P3.3-502**

# 2-D Seismic Reflection Method for Identifying Caverns Generated by Underground Nuclear Explosions in Synthetic Data

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Underground nuclear explosions create cavities and zones of fractured rock, which can be detected using seismic reflection and inversion techniques. This study focuses on using seismic methods in accordance with the Comprehensive Nuclear Test-Ban Treaty (CTBT) protocols to improve the accuracy of cavity detection. Simulations of wave propagation using the Spectral Element Method (SEM) through subsurface structures, including cavities and their surrounding fractured zones, generate synthetic seismic data. Advanced data processing techniques, such as time migration and the addition of precise lithology to the models, based on previous nuclear test sites, are used to analyze seismic reflections and delineate subsurface anomalies. The results demonstrate that the proposed methods can effectively identify cavity dimensions and locations, even in complex geological settings. We also investigated whether it can be determined when an underground cavity is caused by a nuclear test or not. This work highlights the importance of seismic technologies in supporting global efforts to monitor compliance with nuclear test bans and ensure the effectiveness of CTBT verification measures.

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**Online e-Poster Session 1** - Board: 0 / **P3.3-527**

## Automated workflows for rapid understanding of ACT and RES imaging potential in an OSI context

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Resonance seismometry (RES) and active seismic surveys (ACT) can be used during a continuation period of a CTBT on-site inspection (OSI). Given the time-restricted nature of an OSI, semi-automated workflows have been developed for quick understanding of the ACT and RES imaging potential, compatible with the standardized georeferenced data outputs of the current ACT equipment operated by the PTS. The ACT workflow follows a minimalistic processing approach including vibroseis correlation and stacking (as applicable), frequency analysis, CMP geometry creation and velocity analysis leading to generation of a brute stack. The RES workflow assumes that the subsurface cavities, tunnels etc. act as point scatters for distant wavefields or as secondary seismic sources. Under these assumptions, seismic interferometry in the form of auto- and cross-correlation is applied. Both workflows have been tested on data from the OSI 2023 Field Test in the UK and OSI 2024 build-up exercise in Hungary (BUE24). For the UK case, both workflows produce coherent reflectivity from known geological boundaries and visible diffractions originating from known train tunnels. The topography and complex geology of the BUE2024 site make interpretation more ambiguous, however, the results still provide relevant information about the velocity and spectral properties of signals of interests.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 16 / **P3.3-528**

## Results of 2022 and 2023 OSI Field Tests for Non-Seismic Geophysical Techniques

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In 2022 and 2023, the PTS conducted field tests for the development of seismic and non-seismic geophysical techniques for deep on-site inspection (OSI) applications. The 2022 Field Test took place in the Austrian Alps over a cave system in limestone with karst voids 5-15 m in diameter at depths of 40-350 m. Non-seismic methods were deployed over two profiles: electrical resistivity tomography (ERT), frequency-domain electromagnetics (FDEM) and gravitational field mapping (GRV) over one of the profiles (together with seismic methods) whereas only ERT over the second profile. The 2023 Field Test was conducted in the UK on a gentler topography above the Channel Tunnel, with two rail tunnels 7.6 m in diameter excavated in chalk marl at 90 m depth. Together with seismic methods, ERT measurements were conducted over two profiles and GRV measurements over one of them. In both tests, the electrical conductivity measurements reveal detailed subsurface geology, including direct detection of some shallow caves by ERT and the GRV anomalies are consistent with locations of the 2023 targets. Based on the tests, a new GRV workflow was developed for OSI. Joint interpretation of non-seismic and seismic results emphasizes the complementary nature of different techniques and data processing approaches.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 14 / **P3.3-529**

## Subsurface Interpretation Based on Aero-Magnetic and Aero-GPR in the Cipendawa Area, Cianjur

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The advancement of geophysical acquisition technology is currently growing. One of the technologies that we have begun to develop and apply is the Aero-magnetic and Aero-GPR methods that utilize Drone vehicles. We apply this aero GPR acquisition method to coal mining areas and have succeeded in identifying micro fractures, coal thickness to sedimentation in water reservoirs in exploitation areas up to a depth of 30 m below the surface. In volcanic areas, the Aero-GPR and Aero-magnetic methods are able to identify reservoir traps and identify subsurfaces up to a depth of 25 m. Both of these technologies are very promising in identifying subsurfaces or shallow anomalies in an area that does not allow for conventional data acquisition.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 15 / **P3.3-556**

## Results of 2022 and 2023 OSI Field Tests for Seismic Techniques

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In 2022 and 2023, the PTS conducted two field tests for the development of seismic and non-seismic geophysical techniques for deep on-site inspection (OSI) applications. The 2022 Field Test took place in the Austrian Alps over a cave system embedded in limestone with karst voids 5-15 m in diameter at depths of 40-350 m. Active seismic surveys (ACT) and resonance seismometry (RES) were conducted over two profiles, with also non-seismic techniques deployed over the first. The 2023 Field Test was conducted on a gentler topography in the UK above the Channel Tunnel, consisting of two rail tunnels 7.6 m in diameter excavated in chalk marl at 90 m depth. ACT was deployed over two profiles and RES over one (non-seismic techniques over both). These were first OSI activities to employ an ACT system owned and operated by the PTS. The field tests were also specifically designed to test a new concept of operations for RES, involving use of local, regional and teleseismic events as well as ambient seismic noise. The ACT and RES results show unique seismic signals from the targets. Joint interpretation of the seismic and non-seismic results emphasizes the complementary nature of different techniques and data processing approaches.

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**Online e-Poster Session 2** - Board: 0 / **P3.3-560**

## Application of Electroluminescence in a Prototype for the Measurement of a Liquid Argon Scintillation

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The development of equipment for measuring of low levels of argon-37 activity in atmospheric and soil air samples remains a priority task for improving nuclear test monitoring technologies during on-site inspections (OSI), as well as a promising direction for the International Monitoring System (IMS).

In recent years, under a contract with the CTBTO, the Khlopin Radium Institute has been developing a prototype of a setup for measuring low levels of argon-37 activity based on the registration of liquid argon scintillations, a technology traditionally used in particle physics and cosmic rays. Measuring liquid argon samples allows for a significant increase in the volume of argon samples without increasing the size of the measuring cell.

The use of the classical scintillation measurement scheme did not allow reliable registration of argon-37 decays due to the low energy of its Auger electrons. In order to increase the light output, work was started on improving the measuring chamber using the electroluminescence effect and bubble technology. The use of the electroluminescence effect in the prototype for measuring the scintillation of liquid argon allows for a significant improvement in its detection characteristics and thereby ensures measurements of argon-37 activity in atmospheric argon samples at the background level.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 17 / **P3.3-568**

## Particulate and Noble gas data assessment tool for the Working Area (PaNG WA)

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Particulate and Noble gas data collected during the OSI need to be assessed and integrated with the other OSI techniques in order to create a comprehensive report. While the spectra are analyzed jointly with ISP in the OSI Field laboratory on individual sample level, the results of their analysis shall be integrated over the entire Inspection Area and provide the basis for further refinement of the search logic, field mission planning and fusion with data from other techniques. This process will be performed in the Working Area by the Inspection Team and a specialized software tool (PaNG WA) has been developed for this purpose in preparation for IFE. The tool allows the inspectors to visualize the results of the sample level analysis on the Inspected Area map, group the data by criteria such as search zone, field missions, isotopic results (including ratios and calculation of potential zero time), as well as integration with the auxiliary data – meteorological, state-of-health of processing and analysis equipment, physical parameters of the area where the sample has been collected. The tool also provides the opportunity to compare the observations with known release scenarios to help rule out false positive results.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 18 / **P3.3-606**

## Optimizing the initial and multispectral overflight configurations

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The initial overflight (IOF) and the additional overflight (AOF) multispectral (MSIR) configurations for use during an on-site inspection (OSI) have been reengineered to simplify installation, enhance ease-of-use, maximise capabilities as well as streamlining downstream data processing. These changes have been undertaken in compliance with the specifications listed in the First Comprehensive Draft List of Equipment for Use During On-Site Inspections (INF1573 rev1). The reengineered configurations utilise a common positioning antenna (GNSS) and power distribution unit. The initial overflight configuration itself now includes four dedicated handheld video cameras with audio recording possibility, each triggered independently by the inspectors onboard. The track, base map and recordings are displayed on individual inspector tablets with data stored centrally. The AOF configuration for MSIR comprises dedicated imaging devices for the visible, near-infrared and thermal regions of the spectrum. The thermal imaging camera is a cooled photon detector sensing in the 2.0 – 5.5µm range. It also features a lidar and mechanical shutters triggered from inside the cabin. The configuration

has a reengineered display and control panel to facilitate data collection, and the data processing workflow is enhanced through a custom user-friendly application to pre-process data.

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## OSI Radionuclide and Noble Gas techniques development plan past IFE

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This paper presents a draft development plan for Radionuclide Techniques in on-site inspections (OSI) for the years 2025-2027. It outlines key areas of focus, including improvements in subsoil gas sampling methods, the integration of meteorological data into analysis and advancements in software for data processing. The plan emphasizes the need for enhanced usability of sampling equipment, proposing alternatives to traditional Geoprobe systems, such as lightweight manual direct push equipment and compact Geoprobe-like systems for various soil conditions. Additionally, the paper discusses the importance of tamper-proofing field sampling equipment to ensure the Continuity of Knowledge (CoK) on collected samples. It highlights the necessity of assessing large volume detectors and integrating new technologies into existing OSI frameworks. The development steps outlined include training for OSI staff, feasibility assessments for new sampling techniques and the establishment of maintenance and obsolescence management plans for existing equipment. Overall, this plan aims to streamline OSI processes, reduce health and safety risks and enhance the effectiveness of radionuclide detection and analysis in the context of OSI.

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## Field Tests of a Data Transmission System for On-Site Inspection

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In preparation of the next Integrated Field Exercise, and in line with the capabilities developed with past field exercises, action plan project and expert meetings, the section Equipment and Instrumentalization of On-site Inspection division of the PTS has entered into a new stage of development of

its telemetry solution. In 2022, the existing data transmission system had been subject to a series of maintenance, upgrade and training that confirmed its potential use for OSI technique and OSI deployment. In 2023, a field test in Judenburg, Austria, was organized to validate the configuration and the functionality of the OSI telemetry system. And more recently, on September 2024, a specific field test was performed in the vicinity of the TeST Centre Seibersdorf, Austria, to verify the long distance microwave connection. The paper will expose the field tests results and demonstrate how they show advances in OSI operational capabilities. This represents an important milestone before the actual deployment in next Integrated Field Exercise.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 21 / **P3.3-629**

## Noble gas measurements in an OSI, lessons learned from field measurements and BUE24

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Measurements of radioactive noble gases, i.e. isotopes of xenon and argon, are an important part for an on-site inspection (OSI) in detecting an underground nuclear explosion. The first integrated field exercise where the capacity to collect and analyse noble gases exercised was in Jordan in 2014 (IFE14). Since then, the development of methods and systems has improved the capacity for xenon detection. Here, details on the SAUNA Field system are presented, including a rapid deployment configuration (in a flight pod), integration with the OSI software and routines (GIMO) and an automatic inlet. The latter allows for multiple samples to be added simultaneously to the system and at the same time freeing time for the OSI inspectors. These features were tested during the build-up exercise field test in Hungary in 2024 (BUE24). Lesson learned from this, and earlier field measurements, as well as potential improvements for collection and analysis of noble gas during an OSI will be presented.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 22 / **P3.3-635**

## Application of advanced seismic waveform inversion for detection of underground cavities – a case study

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Underground nuclear explosions (UNE) characteristically generate cavities that serve as key indicators during on-site inspections (OSIs). Active seismic methods involving advanced inversion methods are pivotal in detecting these underground anomalies by identifying static signatures associated with the explosion-induced cavities. The seismic waveform inversion technique is adept at resolving complex subsurface structures, including hidden low-velocity layers, which are crucial for cavity detection.
This presentation centres on a case study where joint seismic travel time and waveform inversion techniques were applied to seismic data from a known geological cavity in Eastern Hungary. The results highlight the efficacy of these advanced seismic techniques in practical OSI scenarios. The presentation delves into both the technological opportunities afforded by seismic waveform inversion and the challenges encountered.
The case study demonstrates the capability of seismic inversion techniques to detect subsurface cavities and underscores the broader applicability and potential improvements these methods offer to the field of OSI. This talk contributes to the ongoing dialogue on advancing nuclear verification capabilities through innovative seismic technology by highlighting the challenges and solutions in implementing these technologies.

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# Lessons learned from active and passive seismic surveys at a test site in Romania

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This work presents the methodological framework for MAM Microtremor Array Measurements (MAM) and Multichannel Analysis of Surface Waves (MASW) techniques applied for a test site in Magurele, near the headquarters of the National Institute for Earth Physics. MAM provides information about deeper subsurface layers using low-frequency seismic waves, while MASW utilizes high-frequency surface waves to provide detailed information about shallower layers. These are non-invasive and non-destructive geophysical methods widely applied in site characterization, geotechnical investigations, engineering studies and earthquake hazard assessments. In order to achieve the purpose of this study, we employed a network of fourteen ATOM units with 3-component 2 Hz sensors and a 24-channel Geode array equipped with 4.5 Hz and 14 Hz sensors. The ATOM units were used for both passive (ambient noise) and active (sledgehammer shots) measurements, while the Geode system was dedicated exclusively to recording active surface wave data. Various configurations (L-shape, triangle, circle, linear, irregular arrays with different lengths) were tested to enhance data quality and depth resolution alongside different acquisition parameters (different timeframes for data acquisition, sampling rates). The results obtained from the active investigations performed with both equipments were compared to assess their effectiveness in subsurface site characterization.

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## Onshore oil and gas exploration by an active seismic method using wireless seismic system SmartSolo IGU-16HR3C series

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The IGU-16HR3C, a cutting-edge wireless seismic sensor developed by SmartSolo, offers transformative potential for geophysical applications, particularly in enhancing the International Monitoring System (IMS) seismic stations, improving on-site inspections (OSIs) and adapting for explosion detection. For IMS stations, part of the Comprehensive Nuclear-Test-Ban Treaty's global network, the IGU-16HR3C's high-sensitivity 3-channel geophones and real-time wireless data transmission improve detection of low-magnitude events, while its cost-effective, durable design suits remote deployments. In OSIs, its portability and rapid setup enable high-resolution, localized monitoring of suspected nuclear test sites, with real time data guiding inspectors efficiently. For explosion detection, the sensor's ability to capture distinct seismic signatures —coupled with scalable, autonomous networks — makes it adaptable for identifying nuclear, industrial or volcanic blasts, enhancing event localization and verification. This paper explores how the IGU-16HR3C's modular design, advanced electronics and wireless capabilities address key challenges in seismic monitoring, offering a versatile, reliable tool for global security and scientific research. By integrating such technology, IMS stations gain precision, OSIs become more effective and explosion detection systems achieve greater adaptability, marking a significant leap forward in wireless exploration methods.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 25 / **P3.3-679**

## Identifying, controlling and preventing cross contamination in the OSI field laboratory - Risk Assessment Cross Contamination Tool (RACC)

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The ENEA Laboratory has been working since many years on difficult-to-measure radionuclides and low level activity isotopes. To achieve low level measurement, dedicated equipment is required as well as specific protocols for the analytical plan. During an OSI, a field laboratory will be run to measure relevant OSI radionuclides, in samples collected in the inspected area. The field laboratory will not have the same performances of an off-site laboratory but nevertheless should achieve some requirements. One parameter to be evaluated is the Minimum Detectable Activity that is functional to the equipment and method for different radioisotopes. This parameter helps the inspectors to be confident about the performance of their method and subsequently to proceed to detect an anomaly associated with an OSI relevant event.
Another crucial aspect to pay attention to is to avoid cross contamination of the samples. Several protection actions can be applied to avoid cross contamination: segregation, cleaning, material handling, staff training... Not all these actions are fully applicable during an OSI due to time and resources constrains. We have run some experimental studies to detect cross contamination, applying different scenarios. The results of this exercise and the Risk Assessment Cross Contamination Tool will be presented.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 13 / **P3.3-764**

## Methodology for monitoring the correctness of the transmission of data received from the devices of the CTBTO On-Site Inspectors

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This paper discusses ways to verify the integrity of information transmitted from tablets of on-site inspectors to a server for inspection data collection. Ensuring the integrity of incoming information is critical in on-site inspection work, as the slightest distortion of data, loss or addition of file, distortion of time and date of information collection, substitution or imitation of information transmission may result in incorrect inspection conclusions and incorrect decision. The solution to the problem of checking the integrity of information is not implemented in the on-site inspection at the moment, but this aspect of the information exchange process is one of the most important in the modern world. The options of the trust network using symmetric algorithms and the network without a common secret of the parties and using asymmetric algorithms are considered. We also consider options of authenticating the source of information in case such authentication is required. The approaches described in this paper can be implemented either with minor infrastructure changes or with significant changes depending on additional requirements, such as authentication, that either way do not result in additional time, space and information complexity overhead and thus do not significantly increase the total cost of information transfer.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 2 / **P3.3-780**

# A looped inference approach for more efficient gravitational field mapping during OSI

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Gravitational field mapping (GRV) is permitted by paragraph 69 of the CTBT treaty (1996; UN A/50/1027) for deployment during the continuation period of an on-site inspection (OSI) to look for features relevant to underground nuclear explosions (UNEs), including tunnels used for horizontal emplacements, underground voids and collapse features. Whilst the technique offers one of the best resolutions with depth of permitted geophysical techniques, it requires comparatively long measurement acquisition times, making the typical spatial resolution of the survey sparse, and increases both the time cost and inspection team functionality (ITF) risk of a GRV mission. This paper discusses an approach developed and tested for civil engineering applications using an in-field looped Monte Carlo algorithm and a No U-turn sampler (NUTS) to sample the Bayesian posterior distribution during the survey. The method prioritises sampling in spatial regions where model parameter variation creates the largest forward modelled gravity variation, thus giving the most valuable information on the target location. By using this method to determine the optimum location of the next measurement point, the number of measurements required to achieve a successful survey outcome can be greatly reduced. We present results from OSI specific use cases and assess potential benefits.

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**P3.3 On-Site Inspection Relevant Techniques** - Board: 5 / **P3.3-817**

# Advancing the Onset-Delay-Method for Resonance Seismometry

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Resonance Seismometry is one of the allowed techniques of CTBT that the Inspection team may apply during the continuation period of an on-site inspection (OSI). The intent is to analyse seismic signals (earthquakes, active sources and noise) to detect wavefield disturbances indicative of a cavity or rubble zone caused by an underground nuclear explosion (UNE). However, the technique is only vaguely defined yet.

We present one implementation of Resonance Seismometry, the Onset-Delay Method (ODM), which is designed to analyze data from regional and teleseismic events to further constrain the location of an UNE site to a few meters. In the current version, even small local events like quarry blasts can also be utilized. This greatly enhances the applicability of the method, especially in areas where such anthropogenic sources like quarries and mines are common. We utilize data from the 2022 Field Test near Rotmoos in the Austrian Alps to show an example event and to present possible future refinements to the method.

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**Online e-Poster Session 2** - Board: 0 / **P3.3-877**

## The use of geological and geophysical techniques for on-site inspection, study case: Deep-seated gravitational slope deformations near the active Boconó fault, north of Bailadores, Mérida state, Venezuela

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This work presents the results obtained from the use of geological and geophysical techniques for the identification of large unstable regions, and can be used in on-site inspections within the framework of cooperation and knowledge exchange of the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Deep-seated gravitational slope deformations are slow and of great volume. The analyzed case is a sackung-type landslide, where the movement is slow and occurs in rocks with a high degree of metamorphism, covering about 10 km in length with more active zones and less active zones throughout the region. The study area is located in the west of the Venezuelan Andes, in the La Negra Pass sector north of the town of Bailadores, Mérida state, where one of the most important active faults in the country passes, the Boconó fault. Based on the field missions, the interpretation of aerial views and satellite images, a site was chosen in the deformation zone, where geophysical measurements were carried out using electrical (electrical resistivity measurement) and electromagnetic (ground penetrating radar) methods. It was obtained that the evidence of deformation identified on the surface can be verified in the subsoil from the electrical resistivity tomography and the radargrams generated.

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**P3.4 Integrating Data from Different Monitoring Technologies** - Board: 5 / **P3.4-031**

## Enhancing Detection of Seismic Events through Data Integration of the Local Stations in the Jordan Seismological Observatory with CTBTO - IMS Network

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This study focuses on the importance of data integrating Jordanian national stations with the International Monitoring System (IMS) network of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) in enhancing earthquake and explosion detection capabilities in Jordan. It includes analytical comparison of local and regional events between results that were obtained from the seismic network in Jordan, and that obtained after adding data from IMS seismic stations. The analysis aims to evaluate the locating accuracy of the events. Also, this study will analyze an explosive event in Jordan or in nearby areas which was recorded by local seismic Stations, then analyze the data obtained from some IMS infrasound stations that detected the same event using GPMCC Software and make a comparison between them in order to achieve the most accurate results. In addition, this study will use SeisComp and NDC in a box. Training, techniques and software provided by the CTBTO in a capacity building project in the Middle East supported the efficiency of national and international monitoring in detecting seismic and explosive activities and improved researchers' capabilities in locating the events more accurately.

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**P3.4 Integrating Data from Different Monitoring Technologies** - Board: 7 / **P3.4-517**

## NEMOS – a software framework to simulate the response from nuclear explosion detection networks

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A software framework - Nuclear Event Monitoring Simulator (NEMOS) - has been developed to simulate the response of sensor networks, which are intended to detect, identify and locate nuclear explosions and other nuclear events. NEMOS simulates the response from seismic sensors, infrasound detection sensors and several types of radioactivity instruments (GM - tubes, NaI- sensors; either stand-alone or in the vicinity of an air sampling filter; aerosol stations equipped with an HPGe detector and two types of radioxenon measurement systems). The response models are used in combination with a nuclear source vector and atmospheric transport modelling. When simulating HPGe and NaI detectors, the full spectra is modelled and then automatically analysed using standard radionuclide analysis software. The responses (detection capability and location accuracy) of the seismic and infrasound sensors are calculated using empirical models. Network responses from a large set of simulated explosions are used in a statistical analysis to evaluate different network configurations with respect to verification capability. The analysis includes calculation of parameters such as reporting time, detection and location capability, and the capability to identify whether an explosion is nuclear in nature or not.

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**P3.4 Integrating Data from Different Monitoring Technologies** - Board: 8 / **P3.4-558**

# Seismic Risk Evaluation of Nuclear Research Reactors in Indonesia: Enhancing Monitoring and Nuclear Test Verification

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Indonesia, located at the intersection of major subduction zones and active fault systems, such as the Sunda Trench, Lembang and Cimandiri Faults, is vulnerable to seismic hazards that pose risks to critical infrastructure, including nuclear research reactors.
This study evaluates seismic risks at three reactor sites — Kartini (Yogyakarta), Swabesi (Serpong) and TRIGA 2000 (Bandung) — using probabilistic seismic hazard analysis (PSHA) based on the 2009–2024 earthquake catalogue from BMKG, incorporating data from 6 Auxiliary IMS stations in Indonesia as part of the CTBTO's monitoring network.
The analysis integrates fault-based models, ground motion prediction equations and site-specific soil amplification effects to estimate peak ground acceleration (PGA) for a 475-year return period. TRIGA 2000 faces the highest seismic hazard (PGA ~0.40g), influenced by the Lembang and Cimandiri Faults. Kartini Reactor experiences moderate risk (PGA ~0.35g), while Swabesi Reactor, with a lower PGA (~0.20g), faces significant amplification effects due to soft soils. The results align with Mangkoesobroto (1998) and Parithusta (2018), emphasizing fault-based hazards and soil amplification.
This study explores integrating these reactors into Indonesia's seismic network to enhance low-magnitude event detection linked to underground nuclear tests. Strategically located near active faults, these reactors can strengthen regional monitoring and support nuclear test verification under the CTBTO.

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**P3.4 Integrating Data from Different Monitoring Technologies** - Board: 9 / **P3.4-852**

# CTBT Auxiliary Station Baumata (AS45) Data Quality Using Template Matching Technique and PSD Evaluation

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The Comprehensive Nuclear-Test-Ban Treaty (CTBT) relies on a global network of monitoring stations, including auxiliary seismic stations, to detect and verify seismic events. Ensuring the reliability and quality of data from these stations is critical for maintaining the integrity of the CTBT verification regime. However, noise, signal contamination and equipment anomalies can compromise data integrity, necessitating robust quality assessment techniques. This study focuses on applying the template matching technique for data quality assessment at AS45 by comparing incoming waveforms with a database of predefined templates representing known event types or signal characteristics and Power Spectral Density (PSD) evaluation. By leveraging this method, we aim to detect anomalies, classify signals and identify potential issues affecting data quality. Results demonstrate that the template matching technique and PSD evaluation significantly enhances the detection of low-magnitude events, reduces false positives and provides a reliable mechanism for monitoring station performance. The approach is particularly effective in identifying recurring noise patterns and equipment malfunctions, enabling targeted interventions to improve data quality. This research

highlights the potential of template matching as a scalable and efficient tool for seismic data quality assessment within the CTBT framework.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 1 / **P3.5-028**

## Assessing the impact of urbanization-induced cultural noise on seismic monitoring: a case study of AS118

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Continuous monitoring of environmental and cultural noise levels is critical in selecting and maintaining seismic station sites, especially in regions undergoing rapid urbanisation. Cultural noise is of particular concern for stations near densely populated or industrialising areas, where human activities generate vibrations that interfere with detecting and analysing seismic signals. This paper examines the increasing levels of cultural noise affecting the CTBTO's AS118, as urban expansion and infrastructure development increase background noise levels. Using ambient noise analysis and time series data from the AS118 station, we assess the impact of cultural noise on seismic data integrity and explore mitigation strategies to preserve signal quality. Methodologies for noise filtering and spatial analysis, as proposed by Petronio (2016), were implemented to evaluate the feasibility of isolating seismic events in the presence of high cultural noise. Furthermore, this study incorporates a comparative approach by investigating similar stations located in urbanising environments, following the methodologies proposed by McNamara and Buland (2004). Our findings underscore the importance of ongoing noise assessments to ensure the functionality of seismic monitoring systems in urban areas. The results provide critical insights that could be adapted for other CTBTO stations facing similar challenges worldwide, and that may require relocation.

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**Online e-Poster Session 1** - Board: 0 / **P3.5-037**

## Detection and time variations of infrasound sources using arrays deployed in Lützow-Holm Bay, Antarctica

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Time-space variations of infrasound source locations for three years, 2019-2021, were studied by using a combination of two local arrays in the Lützow-Holm Bay (LHB), Antarctica. The local arrays deployed at two coastal outcrops detected temporal variations in signal frequency content as well as propagating directions during these years. A large number of infrasound sources were detected with many located to the north and north-west directions from the arrays. These events were generated within the Southern Indian Ocean and the northern part of LHB with frequency-content of a few seconds; these "microbaroms" are believed to originate from oceanic swells. From austral summer to fall additional sources are determined to be located to the north-east. These sources might be related to the effects of katabatic winds across the continental coastal area. Furthermore, several impulsive events during the winter had higher predominant frequencies of a few Hz, higher than the microbaroms. Based on a comparison of source locations with sea-ice and glacier distribution from MODIS satellite images, these high-frequency sporadic sources may be cryo-seismic signals associated with cryosphere dynamics near the arrays. The results suggest that infrasound can be used to monitor surface environments in the coastal area of Antarctica.

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**Online e-Poster Session 1** - Board: 0 / **P3.5-038**

## Analysis of Data from Seismic Monitoring Network around Syowa Station, Antarctica

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Seismic observation at Syowa Station (69.0°S, 39.6°E; SYO), Antarctica started since 1959 associated with the International Geophysical Year (IGY; 1957-1958) campaign. Since the establishment of the INTELSAT telecommunication link, digital waveform data have been transmitted to the National Institute of Polar Research (NIPR) for the utilization of phase identification more clearly. Arrival-times of the teleseismic phases, such as P, PKP, PP, PKKP, S, SKS have been detected with reporting to the International Seismological Centre (ISC), then published as "Data Reports" by NIPR. Seismic phase travel-times data incorporated with annual catalogs of detected teleseismic earthquakes are particularly focused on, along with data utilization for public usage. Recorded waveform data, seismic-phase travel-times and corresponding earthquake catalogs have sufficient quality for many analyses involving dynamics and structure of the Earth viewed from Antarctica. The continuously recorded data for a few decades after IGY have been utilized not only to the lithospheric studies but also to the Earth's deep interiors, which has significant contribution to the Federation of Digital Seismological Networks from a high southern latitude. In this presentation, advances in seismic observation networks and data analysis around SYO and surrounding regions in Antarctica are introduced associated with scientific linkages with other regional and global networks.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 2 / **P3.5-050**

# Data quality control of P- and S-wave picking of local earthquakes

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For the accurate determination of local earthquake hypocenters, it is necessary to have reliable and good quality P- and S-wave readings. Data quality control is an important step to correct or filter anomalies that can occur during phase picking. The Chatelain method (Chatelain, 1978) is first applied to facilitate VP/VS ratio calculation. This method is based on calculating the differences between P- and S-waves arrival times between all stations that record the same earthquake. The plot on the same graph of all S-phase differences vs P-phase differences between each pair of stations for all the studied earthquakes over a region in which the VP/VS ratio is supposed to be uniform is used to get the average VP/VS ratio. We then check the points that are outside the scheme, and evidence phase picking anomalies that need to be checked and provide corrections at the concerned station.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 3 / **P3.5-073**

# Application of the short time statistical analysis in significantly increasing the signal to noise ratio of inrasound, acoustic, hydroacoustic and seismic signals

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Data recorded for monitoring a global nuclear-test-ban treaty are a mixture of useful signals, ambient and measurement noise. Suppressing these noises and increasing the signal to noise ratio is a significant task. The paper describes a way to suppress the mentioned noises, so that by applying the proposed method, the signal to noise ratio is increased by more than 20 dB. This result is achieved by applying the so-called statistical filter, whose operation is based on the application of fourth-order cumulants. The method enables de-noising of signals with or without overlapping time intervals.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 4 / **P3.5-099**

# Algorithm for on-site estimation of the time of arrival of impulse phenomena without the man in the loop

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Acoustic, hydroacoustic and seismic signals that are most often of practical interest are those whose nature is impulsive. The appearance of such forms of impulses is a consequence of the sudden release of energy at a location in a relatively short time. Estimation of the time of arrival of these signals, on several spatially distributed sensors, enables locating the place where these phenomena occurred, which is of particular importance. An algorithm has been developed that enables the time of arrival of impulse occurrence to be estimated on-site, without a human in the loop, and this has been demonstrated in many cases. The paper describes the algorithm, which time interval of the signal additionally segment and statistically analyse by calculating the variance, that is, the cumulative value. If the dynamics of the change in amplitude of the signal meets the adaptive limits, which are reached by analysing each individual time interval, the estimation of the arrival time of the amplitude front is approached by analysing the steepness of the cumulative variance of the observed segment of the signal.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 5 / **P3.5-140**

# Automatic determination of the detection threshold of CTBTO seismological network

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The effective detection threshold of the CTBTO seismological network is a key tool for prioritizing repairs of primary and auxiliary seismic stations. However, many seismic networks implement it manually or semi-manually, using programs that delay the calculation and visualization process and are prone to errors.

This study aims to develop an algorithm to automate the calculation of the effective detection threshold, generating maps in seconds and allowing updates whenever a station goes offline, evaluating its evolution against the desired theoretical threshold.

The algorithm will be validated with local networks and compared to previous CTBTO studies and other networks. The results will determine the minimum detectable magnitude globally, i.e., the smallest seismic event detectable by at least three CTBTO seismic stations.

This automation optimizes time, reduces errors, and strengthens the CTBTO's seismic monitoring capabilities, significantly contributing to the global detection of seismic events.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 6 / **P3.5-144**

## The application of artificial intelligence in exploration seismology

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Recently, involving the capabilities of artificial intelligence (AI) to solve problems in exploration seismology attracted increasing interest. One example is the use of recurrent neural networks to estimate seismic activity. These networks can process time-series data, allowing to model dynamic processes through time-dependencies. Clustering to segment seismic data helps identify different rock layers and their characteristics. Regression models help in estimating rock properties based on geophysical measurements. Additionally, deep learning techniques such as convolutional neural network have been successfully applied to interpret complex geological images. Studies of the geological environment using seismic and seismological data acquire a wide scope. Modern seismic exploration faces the challenges of automating processes and increasing the reliability of results in regions with complicated geology. Specific examples illustrate the application of AI in geophysical workflows, highlighting the results in seismic processing, reservoir characterization, seismic interpretation. In this study, we attempted to conduct joint interpretation of seismic data and earthquakes to determine P- and S-wave velocity models in the South-Caspian Basin (Azerbaijan). The application of AI in geosciences opens up new opportunities for data analysis, modeling and prediction of natural phenomena. AI can significantly accelerate research processes, improve the accuracy of results and expand knowledge of the Earth.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 7 / **P3.5-171**

## Integrating Seismic and Infrasound Technologies for Discriminating Tectonic and Quarry Explosions in Southeastern Brazil

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Discriminating tectonic events from artificial ones poses a significant challenge, particularly when both sources are small and geographically close. This issue is common in regions with quarries for rock blasting and tectonic seismic activity. This study focuses on distinguishing tectonic events from quarry explosions by integrating seismic and infrasound data collected from stations in Sete Lagoas, Minas Gerais, southeastern Brazil. The region experiences low-magnitude natural and anthropogenic events, which are often difficult to differentiate. Properly identifying these events is crucial for understanding anthropogenic processes, assessing risks, forecasting impacts, and mitigating environmental damage.
The NDC in a box software, along with SEISAN and SeisComp software, was used to evaluate signals, correlations, locations and magnitudes. The application of infrasound technology plays an important role in event discrimination by detecting acoustic signals typically associated with quarry explosions, while low-magnitude natural tectonic events (M < 3) are generally characterized by the absence of such signals. Additionally, focal mechanism determination contributes to the characterization of stress orientation and fault plane solutions. This comprehensive approach, combining seismic and infrasound technologies, enhances the ability to identify seismic patterns, differentiate between tectonic and artificial sources, and deepen the understanding of local phenomena and their environmental implications.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 8 / **P3.5-177**

## Mathematical morphological filtering with a self-adaptive reconstruction technique and application to local seismic data

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Recorded seismic data are generally contaminated by noise from different sources, which masks the signals of interest. We implemented a noise suppression approach based on the mathematical morphology theorem. The method involves compound operations of dilation and erosion using structuring elements of varying lengths and decomposes an input noisy waveform into several time functions with differing characteristics. The filtered waveform is constructed from the time functions using a self-adaptive reconstruction technique. Application to a data set of >4700 local waveforms suggests that the implemented mathematical morphological filtering (MMF) approach is efficient for data with low SNR and significantly outperforms frequency filtering, the standard method for noise suppression, in that SNR range. For most of the dataset, frequency filtering results in higher SNR values compared with the MMF method. However, for ~42% of the waveforms, MMF outperforms frequency filtering. The SNR gain achieved with MMF is as large as 23 db. Our results suggest that in an operational setting, MMF cannot replace frequency filtering; however, signal detection can be improved if MMF is used to supplement frequency filtering. MMF could help detect signals in problematic low-SNR data, which are currently being missed when using frequency filtering alone.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 9 / **P3.5-179**

## Using nonlinear thresholding of Stockwell transforms to denoise seismic waveforms

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Stockwell transform, commonly known as S Transform (ST, Stockwell et al., 1996) is an extension of the continuous wavelet transform (CWT) and involves an inverse frequency-dependence of the localizing Gaussian window as well as a modulating phase factor, which result in better frequency resolution than CWT or short-time Fourier transform (STFT). We are leveraging that advantage by implementing an S Transform thresholding method for noise suppression in seismic data. Because of the better frequency resolution provided by the S Transform, combined with the proven efficiency of thresholding methods in improving the signal to noise ratio in general, we expect the S Transform-based thresholding approach to be superior to standard methods and the previously developed CWT thresholding. The approach should lead to better downstream products, including improved signal detection and event characterization.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 10 / **P3.5-184**

## Geophysical Monitoring System interactive analysis updates

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Sandia National Laboratories is developing the Geophysical Monitoring System (GMS) for modernization of the United States National Data Center waveform processing system. The GMS development effort is now focused on development of interactive analysis capabilities (IAN) to replace the ageing Analyst Review Station. IAN now includes capabilities to filter, rotate, and beam station data; measure the azimuth and slowness of signal detections using frequency-wavenumber spectra; and create and locate events using a processing service based on the open source LocOO3D software. IAN is built with modern web technology, with user interfaces accessible using a common web browser. All displays are fully synchronized with a consistent user experience. GMS is deployed using a cloud-ready Kubernetes containerized platform, hardened for cyber security accreditation. The United States is providing the common architecture and processing components of GMS as a contribution in kind to accelerate progress on International Data Centre re-engineering. Open source releases are available on GitHub. This presentation describes the current GMS interactive analysis design and capabilities.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 11 / **P3.5-191**

## Advanced frequency-wavenumber analysis in the Geophysical Monitoring System

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Sandia National Laboratories is developing the Geophysical Monitoring System (GMS) for modernization of the United States National Data Centre waveform processing system, now focused on development of interactive analysis capabilities (IAN). The United States provides open source releases of GMS software to support International Data Centre (IDC) Re-engineering. The latest GMS release includes a new advanced frequency-wavenumber computation capability and user interface that enhances analyst efficiency and accuracy for measurement of azimuth and slowness of a signal detection. The analyst can view thumbnail images to make a quick decision about which detections need review. GMS computes multiple frequency-wavenumber spectra over a time interval near the detection, allowing the analyst to quickly see how the signal evolves. To help assess the quality of the signal detection and best arrival time, the IAN display shows an frequency-wavenumber beam segment computed with the current azimuth/slowness measurement, as well as traces of the maximum frequency-wavenumber spectrum power, azimuth and slowness over time. For best performance in the IAN environment, all computations are performed locally in the user interface, using C/C++ code compiled to web assembly. This presentation describes the GMS frequency-wavenumber software and user interfaces.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 12 / **P3.5-207**

## NPLoc: A Machine Learning Model for Earthquake Location in Permanent Seismic Network

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We present NPLoc, a machine learning model designed to accurately locate earthquakes within a permanent seismic network. This model predicts earthquake origin time, hypocenter, magnitude and its associated uncertainties as rapidly as possible. This approach uses temporal patterns extracted from earthquakes within a seismic network and utilizes the Histogram-Based Gradient Boosting method. To validate the robustness of this approach, we generated a synthetic earthquake bulletin, based on standard seismic network configurations incorporating station distributions with varying amounts of P and S phases and amplitudes for each earthquake. Temporal patterns (relative differential P and S arrivals) and amplitudes from these events served as input data, with earthquake location, origin time, magnitude, uncertainties and azimuthal gap as label data. We constructed three datasets with varying levels of data completeness and assessed the model's performance using Mean Absolute Error (MAE) and Median Absolute Error (MedAE). Results demonstrated the model's accuracy in predicting event properties, with predicted values closely matching actual ones. Furthermore, statistical parameters such as uncertainties and azimuthal gap exhibited minimal MAE and MedAE, highlighting the model's reliability. These findings affirm that NPLoc is robust and effective, even in the presence of significant missing values, demonstrating the model's adaptability in handling incomplete data.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 13 / **P3.5-226**

# Effect of atmospheric entry angle on uncertainties in the observed infrasound signal back-azimuths

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Infrasound sensing is essential for the global detection and precise geolocation of bolide events. However, discrepancies often arise between observed back-azimuths — the arrival direction of infrasound signals — and theoretical predictions based on the bolide's peak brightness location, especially for shallow angle entries. Shallow entry angles result in complex, extended acoustic signals along the atmospheric path, with various trajectory segments detected by infrasound stations, causing significant variability in back azimuth residuals (differences between observed and theoretical values). This study investigates how the bolide entry angle influences azimuth variability up to 15 000 km. We developed a model to quantify the impact of entry angles on back-azimuths, showing that shallow entry bolides can lead to substantial deviations, challenging accurate geolocation over long distances. In contrast, steeper entry angles produce more consistent azimuth measurements, reducing uncertainty beyond certain ranges. These findings stress the importance of accounting for trajectory geometry in infrasound analysis to refine bolide detection and characterization, advancing geolocation accuracy and contributing to planetary defense efforts. This framework can also aid in interpreting high energy atmospheric events, such as spacecraft re-entries, where precise geolocation is critical.
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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 14 / **P3.5-245**

# Event location in the Geophysical Monitoring System

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Sandia National Laboratories is developing the Geophysical Monitoring System (GMS) for modernization of the United States National Data Center waveform processing system, now focused on development of interactive analysis capabilities (IAN). The United States provides open source releases of GMS software to support International Data Centre (IDC) re-engineering. Sandia has recently integrated event location capabilities into GMS, including an event location service based on the LocOO3D locator that is part of the openly available Salsa3D software package. This service is configured to use the traditional earth models and corrections used at the IDC but can also be extended to use advanced 3-D earth models. IAN now includes a new event location user interface that allows the analyst to view the details and history of location solutions for an event. Analysts can adjust observations and location parameters and compute multiple constrained locations. Sandia has also updated the GMS feature prediction service to be based on Salsa3D software, providing the predictions of travel time, azimuth and slowness to be consistent with the LocOO3D location solutions. This presentation describes the GMS event location software and user interfaces.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 15 / **P3.5-253**

# Recent Updates and New Features in the InfraPy Infrasound Signal Analysis Software

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Monitoring of phenomena in the atmosphere and at shallow depth of burial using infrasonic signals is often performed via automated detection, localization and characterization with refinement using interactive tools for an identified event of interest. Ongoing infrasound research and development at Los Alamos National Laboratory includes development and evaluation of various signal analysis algorithms as well as refined user interfaces and workflows. These tools are bundled into the open source InfraPy software suite. Single channel detection based on spectrogram and density based clustering has been investigated with promising results for analysis when coherence-based detection is not possible. Propagation likelihoods have been modified to enable inclusion of detections lacking direction of arrival information in localization analysis. Also, an event-specific localization method leveraging time-reversed infrasonic ray tracing is being actively evaluated for use as the next generation to the Bayesian Infrasonic Source Localization framework. Lastly, in addition to

existing command line and graphical user interfaces, an automated pipeline capability is being developed for network level monitoring applications. Database connectivity is being explored for all user interfaces to store analysis results in a familiar structure for geophysical monitoring SMEs. An overview of the InfraPy algorithm suite, various user interfaces, data I/O, and workflow options will be presented.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 16 / **P3.5-269**

## Assessment of the impact of interactive analysis on Primary Array Seismic stations detections associated with building the automatically produced SEL3 events

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The ability of automatic data processing at the CTBTO results in identifying and estimating parameters for phases detected by the IMS stations. These processes contribute to provide automatic event locations generating the Standard Event List3(SEL3). During interactive analysis, the SEL3 event solutions are refined by modifying, or re-estimating phase attributes. These actions include: (1) adding new phases, (2) disassociating phases, (3) renaming phases, (4) re-timing phases and (5) re-estimating phase parameters for azimuth and slowness.
Here, we evaluate the outcomes of these interactive actions and the statistics of phase modifications performed during 2023 and 2024. We found the following numbers (percentages) of phases were modified in 2023: 73 937(20.7%) by adding, 30 603(14.2%) by disassociating, 117 034(32.8%) by renaming, 115 695(41.8%) by re-timing and 79 835(28.8%) by re-estimating phase parameters. These modifications led to the rejection of several SEL3 events due to invalid detections or recorded by fewer than three seismic stations. The remaining SEL3 events, improved in quality, were validated and saved as LEB/REB bulletin.
Our analysis shows that a substantial number of phases associated with SEL3 events require modification, underscoring the need to enhance automatic data processing. Improving these processes would reduce the interactive analysis workload and ensure the timely production of the REB.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 17 / **P3.5-280**

## The Swedish National Seismic Network

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The Swedish National Sesmic Network (SNSN) currently operates 80 broadband seismic stations. In addition, SNSN receives real time data from about 120 stations located in Norway, Finland, Denmark, Germany, Poland, the Baltic States and Russia. SNSN processes the waveform data of this virtual network using the SeisComp and Earthworm systems in parallel. In order to screen out spurious events, we generate a common bulletin which contains events that have been located by both systems independently. The common bulletin is very reliable (3 spurious events during the last two years), captures events down to about ML = 1 and contains almost all events with ML > 1.5 in Fennoscandia. Events of the common bulletin are automatically classified by an artificial neural network as earthquakes, blasts or mining-induced events. The classifier has been developed at SNSN and was implemented during 2023. Comparing the automatic classification with analyst-reviewed classification, we found a 97% match
The real time automatic common bulletin is available as a simple interactive webpage for the general public, and in quakeml and nordic format for the seismological community. SNSN is forwarding complete event parameters for all earthquake events with ML >= 2 to the European-Mediterranean Seismological Centre.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 19 / **P3.5-317**

# Advancing Earthquake Localization Using Deep Learning in Gas Storage Fields

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The identification and precise location of earthquakes are essential for understanding seismicity and mitigating associated risks. This research focuses on utilizing state of the art deep learning methods, specifically PhaseNet, to enhance the accuracy of seismic phase picking and event localization. By analyzing 19 years of continuous seismic data from a gas storage field in Iran, our study aims to develop a comprehensive catalog of induced seismic events. PhaseNet, with its advanced neural network architecture, enables robust phase detection even in noisy environments, making it highly effective for regions with industrial activity. This methodological framework aligns with the themes of the SnT2025 Conference, emphasizing innovative approaches to seismic monitoring and data analysis. Our work demonstrates the potential of integrating artificial intelligence with seismic data processing to improve real time monitoring and risk assessment of gas reservoirs. This research not only addresses scientific and technical challenges but also provides critical insights for industrial applications, contributing to enhanced safety and management of strategic energy resources.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 20 / **P3.5-329**

## Earthquake Location Capability of the Thailand Seismic Network

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The performance of earthquake detection and localization within the seismic network of Thailand was analyzed, encompassing the Thai Meteorological Department (TMD) network, which serves as the main authority for monitoring seismic activity in Thailand and adjacent regions, along with the seismic network of the Department of Mineral Resources (DMR) and the CMAR array of the CTBTO. The minimum magnitude is influenced by the seismic noise present at the seismic station as well as the distance between the earthquake and the station. A total of 173 seismic stations distributed throughout the country were used for calculation of a P-wave impulse amplitude recording at station that is higher than the seismic noise level of the station to estimate the detection threshold of the seismic station or the magnitude of completeness Mc of seismic network. Based on data from at least 4 detecting stations, the average magnitude of completeness for earthquake localization in the Thailand seismic network is ~2.9. The Northern part has the lowest Mc of 2.3, especially in Chiang Mai Province, we can locate earthquakes with a magnitude of less than 1.5 due to a dense station, including the CMAR array, which is utilized in the calculations.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 21 / **P3.5-340**

## Automatic event detection and localisation using 3C array and denoising by Principal Component Analysis

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In order to be able to detect and characterize small magnitude events, even those with long propagation distances, seismic arrays are perfectly adapted tools with their high detection capabilities. We have studied the possibility to improve the detection and the localization of local and regional seismic events by using data from only one array.

International Monitoring System seismic arrays are predominantly formed using multiple vertical sensors with a single three-component (3-C) seismometer co-located at one site. The deployment of fully or partially 3-C seismic arrays, such as FINES array in Finland, ARCES array in Norway or SPITS array in the Svalbard archipelago, offers the possibility to take additional advantage of the coherency on the horizontal components. For the case of S-phases, this has the potential to significantly improve their detection and characterization.

Despite their numerous advantages, 3-C arrays are still afflicted by coherent and incoherent noise. Trying to address this issue, this study aims at quantifying the improvement in event detection and localisation when denoising the data beforehand using a Principal Component Analysis approach and/or using three-component data.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 22 / **P3.5-342**

# Earthquake-Nuclear-Explosion Discrimination Using Discrete Wavelet Transform Machine Learning (DWTML) Supervised Techniques

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Accurately distinguishing between nuclear explosions and earthquakes by manual discrimination or automatic discrimination is crucial in the field of seismic signal analysis. The technique of manual discriminating takes a lot of time, and it can occasionally become inaccurate. Thus, a high-accuracy automatic discrimination method is required. An inaccurate assessment of inherent seismicity of a region can result from falsely differentiating between nuclear explosions and earthquakes. Multi resolution analysis (MRA) of Discrete Wavelet Transform (DWT) has emerged as an innovative approach to differentiate between seismic activities caused by earthquakes and those triggered by nuclear explosions. This multiscale analysis provides rich feature sets that enhance the performance of various machine learning (ML) techniques, such as Support Vector Machines (SVM) and Random Forests. These algorithms have been trained on the distinct spectral signatures and temporal characteristics discerned from the wavelet-transformed data, allowing for precise classification. Utilizing waveforms from 295 nuclear explosions and 369 earthquakes, the proposed algorithm attains an 83% discrimination accuracy.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 23 / **P3.5-365**

# Infrasound Analysis of the 6 February 2023 Kahramanmaraş Earthquakes Using CTBTO Arrays

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On February 6, 2023, at 01:17 UTC and 10:24 UTC, two devastating earthquakes with magnitudes of Mw 7.7 and Mw 7.6 struck, with epicenters located in Pazarcık (Kahramanmaraş) and Elbistan (Kahramanmaraş), respectively. These earthquake couples are one of the most destructive earthquakes occurred in recent history affecting 11 provinces in Turkey's Southeast region and causing more than 53 000 casualties in Türkiye. Earthquakes cause a total rupture length of 300 km along the East Anatolian Fault Zone. These two main events were also recorded by infrasound stations of the International Monitoring System (IMS) under the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), at distances ranging between 2000–3000 kilometers. The analysis of these events was conducted with the DTK-GPMCC and Geotool applications of NDC in a box software suite developed by the Provisional Technical Secretariat (PTS) for use at National Data Centers (NDCs).

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 24 / **P3.5-387**

# Deep learning based phase picking on seismological IMS stations

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We present our work on training and the application of deep learning algorithms for the automated phase picking of body waves on the the IMS network. We train new IMS data based seismic phase pickers from both EQTransformer and PhaseNet architectures. Phase picking is a necessary step before event localization and characterization and deep learning based models have been proven to perform well at this task. PhaseNet and EQTransformer are two prominent state-of-the-art phase picking algorithms that have been retrained on several different datasets. Waveform data from primary and auxiliary stations is used in the training and evaluation. For training we use good quality picks from REB events between 2013 until 2023. We evaluate the performance in comparison with unseen evaluation REB phase picks and manual phase picks. We compare the performance with applying other pre-trained phase pickers to the IMS data to determine if already pre-trained models can be used satisfactorily out of the box for seismological IMS data. We also evaluate the generalization ability of the two IMS data trained models by applying them to other non-IMS seismological stations.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 25 / **P3.5-392**

## Investigating the seismicity around the DPRK test site

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The Punggye-ri nuclear test site in North Korea, historically not seismically active, has likely experienced significant stress changes from the six nuclear tests, particularly the largest in 2017. These stress changes have facilitated the triggering of seismicity in the surrounding area long after the tests. Using multi-channel correlation detectors (Gibbons, 2012) at the IMS seismic arrays KSRS (South Korea) and USRK (Russia), we detect seismicity down to magnitudes < 2 close to the test site. Continuous data from KSRS (since 2006) and USRK (since 2008) allow us to construct a detailed timeline of seismic events, for which we analyse their signal characteristics and compare with the six nuclear tests. A subset of these events, precisely located in published studies, serves as a reference for our correlation analysis and clustering, which identifies five main clusters. Linking these clusters to the published locations allows us to infer the regional distribution of seismicity and its connection to stress changes induced by nuclear testing. This work enhances understanding of how large underground nuclear explosions can alter stress regimes and induce seismic activity, even years after testing, providing valuable insights into the long-term effects on the crust around nuclear test sites.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 26 / **P3.5-396**

## Analysis of the seismic event to the northwest of Costa Rica and events detected with the Portable Infrasound Station I69CR, including data from IMS stations

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In this study on the use of IMS station data, the seismic event of October 12, 2024, at 17:43 UTC, in the northwest of Costa Rica will be analyzed, using nearby seismic stations and including non-IMS stations from the local OVSICORI-UNA network. Additionally, the results of the analysis of the main infrasound events detected by the portable array station I69CR will be presented, along with data from nearby IMS infrasound stations in Costa Rica. The main infrasound events detected include the

Aguas Zarcas meteor event on April 23, 2019, one of the unique events recorded in an infrasound network in Costa Rica, and the infrasound event in southern Puerto Rico on June 23, 2019, recorded by station I69CR and IMS infrasound stations.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 27 / **P3.5-408**

## Application of UMAP and XGBoost to Pg and Lg wave amplitudes, waveform time series and spectrograms to identify Mining vs Earthquake Events

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Low magnitude monitoring of explosions is an expanding field of interest, but due to low SNR and station coverage it is difficult to identify them. We hope to explore these limitations by using simple features from regional events and easy to implement machine learning algorithms to classify earthquakes vs explosions. Using the CNRST bulletin, we collected 4542 regional waveforms for both mining and non-mining events occurring around the station MD31. Using these events, we selected 260 mining and 161 non-mining events to conduct this study. We processed these waveforms to construct RMS amplitudes of Pg and Lg in five frequency bands at 4-6, 6-8, 8-10, 6-12 and 8-16 Hz, timeseries at the same frequencies and spectrograms. The high-frequency Pg/Lg amplitude ratios separated the two population quite well. The supervised 80:20 and 50:50 training and testing of data and analysis of the impact factor of the attributes using the XGBoost algorithm illustrated a high level of success in identifying the source types. Using a supervised trained 90:10 model, we could further identify additional source types for about 428 events in the area. We are currently creating models based on the waveform time series and spectrograms for comparison.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 28 / **P3.5-423**

## Application and Evaluation of Deep learning Phase Pickers for Local Aftershock Monitoring

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The use of Machine Learning (ML) methods in seismology has gained significant attention in recent years, driven by the availability of large, high-quality datasets. While ML is applied to various seismological tasks, it is most commonly used for seismic signal detection, phase picking and classification. Recent studies show that deep learning models such as EQTransformer, PhaseNet and Generalized Phase Detection (GPD) perform remarkably well in these areas, often rivaling waveform correlation methods, particularly in low-seismicity regions.
In this study, we applied EQTransformer, PhaseNet and GPD pickers to aftershocks of two moderate earthquakes in Türkiye (Mw 5.7 Marmara Sea on 26.09.2019 and Mw 6.0 Düzce on 23.11.2022). Their performance was compared with the reviewed Kandilli Observatory catalogue, focusing on the correct identification of P and S phases and arrival time differences between analyst picks and ML outputs. An evaluation of metrics such as precision, recall and F1-score reveals that EQT, PN and GPD exhibit distinct strengths and weaknesses compared to each other and against the analyst reviewed picks when using their original weights and pre-trained models, underscoring the potential benefit of training models with local data.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 29 / **P3.5-429**

# Towards Precision Monitoring: A Scalable CNN-Based Signal Classification Framework

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The increasing volume and complexity of seismic data require advanced techniques for efficient signal classification, particularly in monitoring compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT). This study introduces a robust approach using Convolutional Neural Networks (CNNs) to automate seismic signal classification, significantly improving both accuracy and classification speed. Unlike most traditional methods that rely on separate feature extraction tasks performed by experts, the CNN model autonomously learns and extracts pertinent patterns directly from data, enabling more precise and objective classification. Trained on a real seismic dataset encompassing a diverse range of seismic events, the model achieves impressive performance with classification accuracy exceeding 96%. The approach allows for rapid automated feature extraction and classification with robust handling of noisy and complex data, making it easily adaptable for diverse seismic environments.
Comprehensive implementation details are provided, ensuring scalability and facilitating replication across global seismic monitoring networks, thus contributing to advancements in seismic analysis and global security.

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**Online e-Poster Session 1** - Board: 0 / **P3.5-433**

# Seismoacoustic Monitoring of Pyroprocessing Equipment

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With the projected increase in world nuclear capacity comes the hurdle of spent nuclear fuel. Pyroprocessing is one method to process irradiated fuel by using high temperatures and electrochemical steps to separate radioactive components of interest. High temperatures, high radiation levels and equipment confined to a heavily shielded hot cell are a few of the challenges introduced regarding safeguards for pyroprocessing. The first stage of the process utilizes an element chopper to cut irradiated fuel into smaller pieces, offering the potential to identify equipment operation through seismoacoustic monitoring. Seismic and infrasound sensors were deployed at various locations and distances near a pyroprocessing hot cell to evaluate signals emitted from the chopper. Signals were processed using short-time Fourier transforms and visually scanned to locate chopping events. Operator logs were then collected for ground truth comparison. Results indicate that both infrasound and seismic signals offer the ability to accurately measure this stage of pyroprocessing, though seismic signals are more prominent. This type of monitoring offers a method to aid in safeguards by validating a pyroprocessing facility's schedule and identifying activity that does not align with records.

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**Online e-Poster Session 1** - Board: 0 / **P3.5-442**

# Real Time Earthquake Detection Using YOLOv8 and Spectrogram Analysis

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This research explores the application of the YOLOv8 object detection framework for real time earthquake detection using spectrogram images derived from seismic data. The proposed method is a promising candidate for real time event detection, with the potential to improve detection accuracy and reduce the risk of human error. By leveraging the strengths of YOLOv8, known for its speed and accuracy in object detection tasks, we propose a novel approach to identify and localize earthquake events within seismic signals. The methodology involves: Transforming continuous seismic data into time-frequency representations (spectrograms) and provide annotation mechanism to have labeled dataset, training a YOLOv8 model on a meticulously curated dataset of annotated earthquake spectrograms, and deploying the trained model for rapid event detection and localization. YOLOv8's ability to efficiently process images and generate high-quality bounding boxes for detected objects makes it a promising candidate for real-time event detection. The performance of the proposed system is rigorously evaluated using relevant metrics such as precision, recall and F1-score. This research aims to contribute to the development of more efficient and accurate earthquake detection systems, potentially leading to improved seismic data analysis.

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**Online e-Poster Session 1** - Board: 0 / **P3.5-444**

## Time-variable moment tensor joint inversion of traditional seismic and gradiometer data

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Traditional moment tensor inversions are a common tool used to characterize events of interest for nonproliferation monitoring. Many inversions assume a known source time function and solve for the moment tensor of a seismic source. However, this requires a source time function to be assumed, which could result in inaccurate results if, for example, an explosion source time function is used for data resulting from an earthquake. Additionally, a traditional moment tensor inversion does not allow for the characterization of complex sources that may evolve over time. The time-variable moment tensor approach used in this study does not assume any a priori source time function, and allows for a source that evolves, such as an explosive source that is followed by slip on near-source joints, to be characterized through time. We build upon previous work that inverted traditional seismic data for a time-variable moment tensor result and incorporate seismic gradiometer data into our inversion through a joint inversion framework. The inclusion of gradiometer data allows for additional information concerning the seismic strain field to be incorporated into the inversion, thus allowing us to potentially separate complex source mechanisms depending on the placement of the gradiometer stations.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 30 / **P3.5-468**

## Generation and utilization of synthetic seismograms with the Waveform Simulation Framework

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The generation of synthetic seismograms through simulation is a fundamental tool of seismology required to run quantitative hypothesis tests. A variety of approaches have been developed throughout

the seismological community and each has their own specific user interface based on their implementation. This causes a challenge to researchers who will need to learn new interfaces with each new software they wish to use and create substantial challenges when attempting to compare results from different tools. Here we provide a unified interface that facilitates inter-operability amongst several simulation tools through a modern containerized Python package. Further, this package includes post-processing analysis modules designed to facilitate end-to-end analysis of synthetic seismograms. In this contribution we present the conceptual guidance and an example implementation of the new Waveform Simulation Framework.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 31 / **P3.5-472**

## Detection Capabilities and Picking Precision of Deep Learning Methods for Local Seismic Network Processing: The Case of Terceira Rift, Azores, Portugal

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The production of high-quality event bulletins relies on high-accuracy and high-precision hypocentral locations and low completeness magnitude. The Terceira Rift provides an ideal setting to study rifting processes due to its seismicity and volcanism, driven by slow transtensional deformation between the Nubian and Eurasian plates. This study leverages data from the UPFLOW project, including 49 Ocean Bottom Seismometers and land stations, to improve seismic detection in the region. Traditional land-based seismic networks struggle with detecting smaller events and precise locations using classical methods. By integrating dense networks and employing Machine Learning techniques, such as the EQTransformer, the study aims to enhance event detection and phase picking accuracy. A ten-day dataset from the IPMA network (October 2021) was analyzed using EQTransformer, where waveform pre-processing included removal of instrument response, detrending, maximum taper of 1%, high-pass filter at 2 Hz, and threshold of 0.10 for both P and S. Results show a median pick-probability of ~90% and ~70% for P and S respectively, and picking precision within ±0.5 seconds for P and ±1 second for S phases. Deep learning methods outperformed manual analysis in detecting events in this test, indicating its potential for improving seismic monitoring in regions like the Terceira Rift.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 33 / **P3.5-501**

# The Implications of Limestone Mining to Noise Level on The Site KAPI (CTBTO) with Analysis of Power Spectral Density

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Limestone mining activity close to site KAPI (CTBTO) has been clearly visible through the land clearing from satellite imagery. The BMKG Region IV Makassar team has visited the site to analyze noise from heavy equipment activities that operate around the site, consisting of a bucket excavator on 25 August 2023 and a breaker excavator on 23 January 2024. Noise from the activities of these two types of excavators is recorded by broadband seismometer Nanometrics Trillium 360 (KAPI_00) at depth ± 61 m and Trillium 120 PH (KAPI_10) at depth ± 7 m. The purpose of this study is to analyze the effect of limestone mining activities on the noise level of two KAPI sensors placed at different depths. The background noise on KAPI is processed using power spectral density and compared with the results of background noise recording during quiet conditions on 25 March 2022, before the mining started. The analysis shows an increased amplitude of spectral density for all components at sensor KAPI_00 and sensor KAPI_10 after the operation of mining activities. Other interesting things found that the sensor KAPI_10 have recorded a significant increase in period less than 0,1 s compared to sensor KAPI_00.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 35 / **P3.5-532**

# Deep learning surrogate model for near real-time estimation of ground-level infrasound transmission losses

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Accurate modelling of infrasound transmission losses is essential for evaluating the performance of the International Monitoring System (IMS) infrasound network. The parabolic equation method provides accurate loss modeling but is computationally expensive for operational monitoring applications. To address this, a previous study trained a Convolutional Neural Network on regionally simulated wind speed fields, predicting ground losses nearly instantaneously with a mean squared error of 5 dB. However, it relies on interpolated atmospheric data, which can lead to an incomplete representation of the medium, and only considers wind values, which is not adapted for long-range modelling. In this contribution, we address this by using globally simulated range dependent wind

speed and temperature fields up to 130 km altitude and by optimizing the network. Recurrent layers capture sequential atmospheric dynamics, improving performances. The model achieves an error of 4 dB and provides epistemic and data-relate uncertainty estimates. Validation on reference events (Tonga-Hunga eruption, Hukkakero explosions, etc.) demonstrates the model's generalization capabilities. Predicted attenuation are compared with the one obtained by an alternative version of the model, specialized on a regional scale using fine-tuning. The method also adapts to new frequencies, marking a significant step towards near real time evaluation of IMS detection threshold.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 36 / **P3.5-553**

## Software Engineering Aspects of Modifying and Enhancing NET-VISA to Incorporate Long Term Priors

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The NET-VISA software package features a physics-based probabilistic model combined with a heuristic inference algorithm to identify the most likely set of seismic events corresponding to a series of detections by a global seismic network. It has been enhanced to detect events occurring in three mediums — rock, air and water — and supports seismic, hydro-acoustic and infrasound sensors.
The International Data Centre (IDC) of the Comprehensive Nuclear-Test-Ban Treaty Organization is enhancing its event detection capabilities using NET-VISA. NET-VISA events are added to Standard Event Lists (SEL).
We present efforts to incorporate long term priors into the system. This approach involves generating priors from an extensive dataset spanning approximately five-ten years, capturing averaged network and station behavior across diverse environmental conditions and configurations. The extended training period could yield a comprehensive set of priors, which would then be applied to all processing over periods of a year or longer, ensuring greater consistency in event detection and analysis. We also developed a new metric to evaluate the quality of automated seismic bulletins in comparison to human-annotated ones.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 37 / **P3.5-569**

# An end-to-end LLM engineering platform for fine-tuning, evaluation and registration of custom models and adapters

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We present an end-to-end LLM engineering platform for fine-tuning, evaluation and registration of custom models and adapters. Our platform, built on top of open-source tools, provides a comprehensive suite of components for data processing, fine-tuning, evaluation and deployment of LLMs. Key features include pipeline orchestration for batch-oriented workflows, model training and fine-tuning, inferencing and model serving, model lifecycle management, and monitoring and observability. We demonstrate the versatility of our platform through potential applications such as fine-tuning multimodal open-source LLMs on custom datasets for increased accuracy. By providing a unified framework for LLM engineering, our platform aims to accelerate the development and deployment of custom models and adapters, enabling a wide range of innovative applications across CTBTO's technologies. These adapters consist of small collections of model weights that can be dynamically loaded and swapped onto a common base foundation model, enabling it to specialize itself on-the-fly for specific tasks like SHI and RN. Finally, we discuss potential applications that could make use of this platform such as fine-tuning a vision transformer on CTBTO labelled data (images of waveforms showing detections with captioning).

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 38 / **P3.5-578**

# Enhanced seismic monitoring integrating DAS analysis with conventional seismological analysis

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The rapid detection, location and classification of seismic events, particularly offshore, has become increasingly important in a world where critical infrastructure on the seabed has been the subject of several damaging incidents. Given the intense political focus on the events, it is equally important to provide data to deescalate a situation if events have natural causes as it is to help clarify the cause in case of man-made disruptions. Conventional seismograph networks are almost exclusively installed on land making it challenging to detect small events far from the shore. The rapidly evolving field of Distributed Acoustic Sensing (DAS) where fiber cables on the seabed are used as sensors can reduce the threshold for detection, improve the accuracy of locating events and reliably discriminate the event origin. DAS generates enormous amounts of data with 1 Tb/day and thousands of channels from one cable not being uncommon. Examples will be given on how data recorded on existing fiber cables can be combined with seismograph network data to obtain a more precise solution. As

critical infrastructure on the seabed in many cases is surrounded by multiple countries, international collaboration on rapid data and event exchanges is crucial.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 39 / **P3.5-587**

## CTBTO Link to the ISC Database

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The CTBTO Link to the database of the International Seismological Centre (ISC) is a service provided by arrangement with IDC/CTBTO. The Link provides PTS and National Data Centres (NDC) with dedicated access to long term definitive global datasets maintained by the ISC. Functionality includes specially designed graphical interfaces, database queries and non-IMS waveform requests. This service gives access to the ISC Bulletins of natural seismicity of the Earth, mining induced events, nuclear and chemical explosions (Specifically 1085 nuclear explosions); the ISC-EHB dataset; the IASPEI Reference Event list (GT) and the ISC Event Bibliography. The Link is also a useful tool for accessing historical event data which can be used for training and exercises commonly carried out by the NDCs and PTS.

The searches are tailored to the needs of the monitoring community and allow for area-based searches and comparisons between the ISC Bulletin and the Reviewed Event Bulletin. Additionally known historical nuclear explosions can be searched as a subset of both bulletins. Recently we have updated the waveform previews provided through the link to provide a more comprehensive coverage of available FDSN stations for REB events.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 40 / **P3.5-596**

## Improving Seismic Signal Classification Through Novel Similarity-Based Techniques

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Seismic signal classification plays a critical role in monitoring and understanding seismic activity by attributing each detected event to its source, such as earthquakes, quarry blasts, volcanic events

or nuclear explosions. Traditional methods, such as cross-correlation-based approaches, offer the advantage of not requiring large databases or explicit feature extraction. However, these widely used similarity-based methods often face significant challenges when dealing with complex, noisy real-world signals and exhibit high computational demands. This research presents a comparative study of other innovative and more efficient similarity-based classifiers. The proposed methods prioritize robustness against variability and noise, achieving enhanced accuracy, adaptability across diverse datasets and significant reductions in computational complexity. Extensive experimental validation highlights their superior performance in improving seismic event classification, providing a reliable tool for automated event source identification. This study contributes to advancing seismic data analysis and supports efforts to ensure compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT).

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 41 / **P3.5-600**

## Infrasound source position by using an over-wavelength sensor array

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To study impulse sound of shell explosion position in a far field over 5 km even for nuclear explosion's position. One new way was designed to perform clear spot image of source position with accurate result, that is a reverse beam-forming of burst pulse sound. Meanwhile, time-delay variance used to estimate source's coordinates and sound's average velocity suggested the sound's propagation is unchanging in its path. Simulation was made to check algorithm's stability in a 6 km area with random distributed 66-sensor array with spacing over 100 m. A low side lobe result was obtained. After that, a 30-sensor infrasound array with over 10 kPa detection range was created in a 5 km shooting field with spacing over 20 m to detect explosion impulse sound. Position result is quite good with error less than 5 m.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 42 / **P3.5-611**

## Infrasonic Source location Using the Neighbourhood Algorithm

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The Neighbourhood Algorithm is a grid search method that optimizes a user-supplied objective function over a computational domain using Voronoi cell tesselation. The algorithm is a method for solving geophysical inverse problems with the additional benefit of not requiring the estimation of travel-time derivative information (Sambridge, 1999)

In this application a misfit function for infrasound detections, defined in terms of observed and predicted values of travel time and backazimuth, is minimised using the neighbourhood algorithm with a hypocentral source location hypothesised.

The method is applied to several noteworthy infrasound events.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 43 / **P3.5-622**

## The NDC in a Box waveform data processing tools: current status, recent achievements and future plans

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To support National Data Centers (NDCs) in their ability to process IMS data, the Provisional Technical Secretariat provides the NDC in a box software package. Many NDCs do real time processing of continuous data from IMS waveform technology stations, with a particular focus on seismic monitoring data. This data can be used for verification purposes, as well as for civil and scientific applications. Automated data acquisition, archiving and processing are performed by SeisComP software, whose standard package is supplemented in the NDC in a Box distribution by exclusive CTBTO components and modules. These include tools for data format transformation and event location based on IDC methodologies. For follow-up manual review, including refining event associations and improving location solutions detected automatically, the NDC in a Box offers the Geotool software. Additionally, detailed analysis of infrasound and hydroacoustic detections is performed using another interactive tool, DTK-GPMCC. The development of these components is ongoing, driven by the needs of NDCs for additional functionality, gap-filling and issue resolution. This presentation highlights the current status, recent achievements, ongoing development activities and future plans for these tools.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 44 / **P3.5-628**

# Seismic event processing using the IMS FDSN webservice and SEISAN

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In this presentation, we demonstrate how to use the IMS FDSN web service to download and analyze seismic data. Specifically, we show how to integrate IMS waveforms and phase-picking data with locally collected datasets, and how to process this information to determine event locations and magnitudes.
For our analysis, we utilize the seismic analysis software package SEISAN. SEISAN (see http://seisan.info) is widely used, particularly by smaller seismic networks, students and researchers, for processing data from both permanent and temporary seismic networks. It is also employed by several National Data Centers (NDCs).
The following topics are covered in the presentation:
• Requesting parametric data in QuakeML format for different events.
• Adding parametric data in QuakeML format from IDC FDSN web services into a SEISAN database.
• Requesting metadata in StationXML format from the FDSN web service.
• Integrating metadata in StationXML format from VDMS into a SEISAN database.
• Requesting data availability information from the FDSN web service and using this information for event selection.
• Requesting seismic data in MiniSEED format from the FDSN web service.
• Visualizing MiniSEED data from the IDC FDSN web service using SEISAN.
These topics are also available as presentations on the NDC Forum.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 45 / **P3.5-643**

# Evaluation of Automatic Infrasound Signal Classification via Machine Learning Deployed at the Central and Eastern European Infrasound Network

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Infrasound monitoring usually requires ground truth information from other sources in order to classify a detection. Here, we present an ensemble model that combines a Random Forest trained on simple features derived from the Progressive Multi-Channel Correlation (PMCC) technique with a Neural Network trained on spectrograms calculated from the waveforms to overcome the necessity of ground truth information. The data originates from a subset of the Central and Eastern European Infrasound networks, including five arrays. A dataset consisting of more than 200 000 hand-labeled PMCC detections involves sources such as quarry blasts, oil refineries, industrial and war activity, thunderstorms, and eruptions of Mount Etna. Training, validation and testing were performed to identify the aforementioned classes versus detections with unknown origins. The experience of multi-month automatic infrasound monitoring is shared, focusing on both single-station and network-level processing.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 46 / **P3.5-658**

## A comprehensive exploration of the IDC infrasound pipeline

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At the International Data Centre (IDC) real time data goes through a three-step process to determine if there is an event. These three steps in seismic/hydro/infrasound (SHI) operations are station processing, network processing and interactive review. Inside each of these steps are algorithms that conduct various tasks (e.g. detection, categorization, location). Many of these algorithms, especially for infrasound, have been changed, adjusted or replaced over the years. Here, we delve into the IDC infrasound pipeline from how the process was envisioned in its development to the current iteration and beyond. Over the years, the IDC infrasound pipeline has separated from the other SHI technologies due to the uniqueness infrasound data possesses. For example, Detection and Feature Extraction (DFX) has been replaced by Progressive Multi-Channel Correlation (PMCC) for detections. Elsewhere, Station Processing (StaPro) and libraries in the Global Association (GA) conglomerate have been tailored or rewritten to improve infrasound characterization, and association. The results of this presentation will outline and explain the detailed criteria, thresholds, and parameters of the current IDC infrasound pipeline. Gaining detailed knowledge of the capabilities and weaknesses of the pipeline, future assessments for improvements and demands will be easier to evaluate and implement.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 47 / **P3.5-676**

# Global Detection of Volcanic Activities at the International Data Centre

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Volcanic eruptions generate infrasound, which consists of low-frequency acoustic waves below 20 Hz. This phenomenon is valuable for monitoring volcanic activity, particularly in regions where local sensor networks are impractical. The expansion of infrasound stations of the International Monitoring System (IMS), along with advancements in infrasound data analysis, has improved the detection of volcanic events. This study presents the results from infrasound data analysis and event reviews conducted at the International Data Centre (IDC), focusing on the detection of volcanic activity across various regions and highlights significant eruptions such as the Shiveluch volcano eruption in November 2024. We discuss the integration of infrasound data with other CTBTO monitoring technologies, such as seismic networks, which could enhance the ability to characterize eruptions and assess their intensity. Additionally, we address the challenges in analyzing and interpreting long-duration infrasound signals, often obscured by background noise from environmental sources like wind and ocean waves.
This work underscores the potential of IMS infrasound networks and IDC data analysis to detect volcanic eruptions on a global scale, providing critical insights into eruption dynamics and supporting efforts to improve volcanic hazard monitoring and mitigation.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 48 / **P3.5-683**

# Infrasound analysis in the International Data Centre Operations

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Routine analysis of infrasound data began in early 2010. Since then, analysts at the International Data Centre have reviewed more than 117 700 automatically built SEL3 infrasound events and included 62 700 events in the Late Event Bulletin (LEB). Of these, 34 800 events met the Reviewed Event Bulletin (REB) event criteria. Analysing infrasound data presents several challenges. These include distinguishing between noise and signal, obtaining preliminary location based on one-station observations, or identifying signals generated by the same source that travelled different paths to detecting stations. Most of the events included in the REB are seismic in nature, originating from stationary short-duration sources such as earthquakes or mining blasts. Another challenge in infrasound event analysis is that infrasound sources often move (i.e. bolides) or produce long-duration signals (i.e. erupting volcanoes). This presentation will focus on the procedures used to analyse infrasound events in IDC Operations along with examples of challenges encountered during infrasound analysis.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 49 / **P3.5-684**

## Comparison of KIGAM and IDC REB Analysis Results for Earthquakes Around the Korean Peninsula

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We compared the locations of earthquakes with magnitudes greater than 3.0 that occurred around the Korean Peninsula from 1 January 2010 to 11 April 2024 between the KIGAM (Korea Institute of Geoscience and Mineral Resources) catalog and the CTBTO (Comprehensive Nuclear-Test-Ban Treaty Organization) IDC (International Data Center) REB (Review Event Bulletin) earthquake catalog. We initially selected 425 event pairs by considering the magnitude, location and epicenter time of each earthquake using the Bulcmp program. We reselected 43 event pairs from the high-confidence region, latitude 32–44 degrees, longitude 122–132 degrees, and analyzed them. The IDC REB epicenters were mostly located to the south of the KIGAM epicenters, and especially in the inland, they showed a southwesterly pattern compared to the KIGAM. RSTT_SSSC (Regional Seismic Travel Time Source Specific Station Correction) was applied to re-location for 34 earthquakes that occurred between 1 January 2010 and 11 August 2020 using Evloc program. As a result of applying RSTT_SSSC, the error ellipse area became smaller than before and 75% of cases were less than 1000 km^2. The epicenter location differences also became smaller with moving right and upward. These results show that the accuracy of the epicenter location was improved by applying RSTT_SSSC correction.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 50 / **P3.5-689**

## Understanding phase classification throughout the International Data Centre acoustic pipeline

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At the International Data Centre (IDC), data received from the network goes through a three-step process (station processing, network processing and interactive review) to determine if a combination of detections can be built into an event. One of the major steps in determining if an event

can be built or not is the phase classification of the detected signals. For acoustic data, phases are determined during each process where, in the first two steps, algorithms will automatically name and rename phases based on a set of criteria and thresholds. In the interactive review, analysts can change or rename phases for a final time to build or not build an event. Here, we analyze the number of phase changes at each IMS infrasound and hydroacoustic station and compare the number of detections in each process database to examine how a detection contributes to building an event. Furthermore, the expansion of the operational stations of the network is examined to understand how additional stations have altered the ability of the automatic and interactive processes to classify phases and build events. Ultimately, the results of this analysis can be used to improve the automatic IDC pipeline for acoustic phase classification and building events.

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**Online e-Poster Session 1** - Board: 0 / **P3.5-710**

## Geothermal Energy Exploration and Monitoring in Kenya: Using Geotool to Characterize Seismicity and Seismic Spectrum at the Menengai Geothermal Field

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Geothermal energy exploration has been going on in Kenya for the last five decades for green energy exploitation. Between the month of April and August 2024, 20 seismometers were installed throughout the Menengai geothermal field/Caldera and its surrounding at a radius of 15 km using. The stations were installed with IGU-BD3C-5 Smart solo seismometer, a low-frequency, three-component sensor for three months. Monthly data retrieval was performed based on battery life of the seismometer. 100% of the data, with a good signal ratio, was collected within the months. The data quality was checked using the smart solo quality check for data gaps, GPS status and battery conditions. The seismicity was located using Geotool where four microearthquakes (MEQs) were well located. A spectral analysis of the two of the earthquakes, microearthquakes and local events using Geotool gives a frequency spectrum within the range of 0-25 Hz and 0-10 Hz, respectively. They generally diffuse and maybe associated with a buried singular magmatic source. Further work is ongoing to locate more earthquakes to improve our understanding of the micro-seismicity of Menengai geothermal field.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 51 / **P3.5-739**

## Analysis of the Gutenberg-Richter Law Using CTBTO SEB Data for the Americas Region

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This study evaluates seismic activity in the Americas region over the past five years using data from the Seismic Event Bulletin (SEB) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). By applying the Gutenberg-Richter law, key seismic parameters (a and b) are calculated to estimate recurrence intervals and maximum expected magnitudes for localized subregions. Using magnitude intervals of 0.5, the analysis refines the characterization of seismic activity. Statistical regression is employed to determine a and b values, enabling projections of maximum magnitudes and their probable occurrence times. Results reveal significant variations in a and b across tectonically diverse subregions, highlighting the heterogeneous nature of seismic activity in the Americas. This research demonstrates the effectiveness of the CTBTO SEB dataset for high-resolution seismic analysis and underscores its potential for enhancing regional seismic hazard assessments. The findings provide a fresh perspective on risk management and urban planning strategies in earthquake-prone areas, offering critical insights for disaster preparedness and resilience.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 52 / **P3.5-757**

## Dellys Fireball: Determination of Characteristics Using Infrasound and Seismic Detections

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On the night of 22 November 2022, at 22:22 UTC, a fireball was observed in the sky over Dellys, a town in north-eastern Algeria. According to eyewitness reports, the celestial body was seen travelling from the south-west to the north-east. Two recently installed infrasound stations recorded the signal from this trajectory, enabling the determination of some of the meteor's characteristics. The utilization of Algeria's ADSN seismic network enabled the recording of the event by multiple stations, facilitating the determination of the fragmentation position and the shock wave propagation direction.

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**Online e-Poster Session 1** - Board: 0 / **P3.5-758**

# The Idaho National Laboratory Seismic Network: A Brief History and Overview of Current Capabilities

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The Idaho National Laboratory (INL), located in Eastern Idaho in the United States, has a history of operating nuclear test reactors and is currently designated as a Reactor Innovation Center. The seismic monitoring network began as a single seismic station in 1973 and has grown to include over 100 instruments for the purpose of monitoring geophysical phenomena. As the network has evolved over the years, new technology has greatly expanded the capabilities of the network. Recently, the INL detected a large sonic boom which traversed the INL desert site and was measured across the seismic network as well as a single infrasound station. This presentation will show the analysis of the recent sonic boom as well as provide an overview of the history of the INL seismic network and the current configuration of the network. It will also provide an overview of the future as the network begins to expand the infrasound network for the purposes of explosion monitoring and understanding the seismoacoustic boundary. In addition, we seek guidance on how the INL seismic network and its data and capabilities can contribute to explosion monitoring efforts worldwide.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 54 / **P3.5-792**

# Survey in Deep Learning Approaches for Local to Teleseismic Earthquake Detection and Phase Picking

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Deep learning approaches are effective for earthquake detection and phase picking. However, challenges in existing research include using non-uniform datasets, such as training on limited event distances and excluding noise samples. Models trained exclusively on local events often fail to perform well on teleseismic signals, while models trained only on signals struggle with robustness in the presence of noise. To address these limitations, we constructed a comprehensive dataset based on MLAAPDE, comprising approximately 800 000 two-minute waveform samples at 100 Hz. Half of the samples consist of event data with P, Pn, Pg, S, Sn or Sg arrivals, while the other half are noise samples. Noise samples were selected as two-minute windows with no cataloged phase arrivals before the first P-wave. The dataset spans local (0°–3°), regional (3°–30°) and teleseismic (30°+) distances. We train and evaluate four architectures—U-Net, U-Net with transformer, CNN-RNN and CNN-RNN with transformer—on this dataset. Preliminary results indicate that the U-Net with transformer achieves the highest detection AUC (0.96). Trained on this local to teleseismic dataset, each model demonstrated robust detection across all distance ranges and low residual variability, underscoring the importance of diverse datasets in building generalized and reliable seismic detection models.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 55 / **P3.5-816**

## Impact of feature selection in the classification of seismic events with machine learning techniques

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Discrimination between explosions and earthquakes is a major challenge in the field of seismology. This task is important not only to meet the expectations of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) but also to refine seismic bulletins used in regional seismicity research, seismotectonic analysis and seismic hazard assessment.
Seven models using different machine learning algorithms (logistic regression, support vector machine - SVM, K-nearest neighbours, decision tree, random forest and Naive Bayes) were trained by selecting all specific features in REB bulletins and acceptable performance metrics were obtained in the test phase. However, after performing a feature selection analysis, removing irrelevant and redundant features, and adding features from the waveform without parametric changes in the models, the performance metric increased significantly.
Meaningful evaluation metrics were used to assess the machine learning models, including accuracy, precision, recall (sensitivity), F1 score and ROC curve.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 56 / **P3.5-818**

## Influence of Event Definition Criteria (EDC) on IDC SHI products and possible approaches to optimize it

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We assess the impact of the Event Definition Criteria (EDC) on the IDC bulletins from the perspective of introduced changes in IDC processing and growing number of IMS stations during the last decade.

Two main changes in IDC processing contributed to the increase SEL3 events reviewed by analysts – infrasound processing since 2016 and introduction of NET-VISA as additional associator to Global Association (GA) algorithm since mid 2017. 90% of the SHI IMS network segment is certified and around 87% is currently operational.
We also observe a growing discrepancy between number of events in the Late Event Bulletin (LEB) and the final product of IDC REB, starting from 4% in 2002 to 18% in 2011, reaching 25% in the last 5 years. Our analysis shows that most frequently LEB events do not meet EDC requirement for three primary stations.
Accumulated experience in processing and analysis over last ten year provides sufficient data to revise existing EDC and propose alternative approaches focused the quality of the products for verification purposes. We discuss possible ways to increase the number events in REB by changing of the EDC and/or using an alternative approach to these criteria.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 57 / **P3.5-855**

# High-resolution analysis of spatio-temporal ambient noise variations across the IMS infrasound network

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Temporal variations of the noise conditions constrain the ability to detect and identify signals of interest at infrasound stations. Station-dependent factors that contribute to the noise include wind and turbulence. A coherent source of ambient noise at the global infrasound station network of the International Monitoring System are microbaroms from the oceans, which vary seasonally such that most stations observe the maximum noise during local winter.
For a realistic estimate of the station noise statistics, we computed the power spectral density (PSD) at all elements of the operational IMS stations on an hourly basis over a six-year period (2019-2024), resulting in more than 15 million computed PSDs. This systematic processing of the background noise allows an assessment of the sensitivity of each measurement system to geographic and environmental parameters that include both wind-generated noise and coherent signals from geophysical and anthropogenic events. Using this unique high-resolution PSD dataset, we analyse the spatiotemporal noise variation across the IMS network and examine local effects at the array sites such as vegetation or snow cover that also contribute to the noise level. This work aims at updating earlier statistical ambient noise models and facilitating detection capability simulations with high temporal resolution.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 58 / **P3.5-869**

# Evaluating the Contribution of Scanning Processes to the International Data Centre Seismic Event Bulletins

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The accuracy and completeness of the International Data Centre (IDC) seismic bulletins, such as the Late Event Bulletin (LEB) and Reviewed Event Bulletin (REB), are essential for global seismic monitoring of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). This study assesses the contribution of scanning processes for missed events during the interactive analysis and their integration into the LEB and REB. The geographic distribution, size and depth of scanned events are analyzed. Additionally, the contributions of individual stations to the detected events through scanning are examined, identifying stations with a high number of detections as well as those with fewer detections. The findings demonstrate that scanning significantly enhances the LEB and REB by identifying overlooked events, improving bulletin completeness. However, this study will explore and recommend possible improvements to enhance the SEL3 automatic production process. Reducing the number of missed events during automatic processing can minimize reliance on scanning, leading to a reduced workload for analysts while maintaining high bulletin quality. This assessment underscores the critical role of scanning in ensuring comprehensive seismic monitoring. It offers actionable insights for optimizing the balance between automated and scanning processes to improve efficiency and accuracy in seismic data analysis.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 59 / **P3.5-882**

# Statistical Comparison between the SSEB and the REB

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The Standard Screened Event Bulletin (SSEB) is a sub-sequent automatic product of the Standard Screened Bulletin (SEB) produced by the International Data Centre (IDC). The SEB is a post-location processing of the Reviewed Event Bulletin (REB) that includes the event characteristics that are used to screen out seismoacoustic events generated from natural or non-nuclear man-made phenomena. The events characteristics are compared with IDC event screening criteria and those that pass the screening are included in the SSEB. This study presents a statistical comparison between the SSEB and the REB after 24 years of bulletin production. The comparison takes into consideration the progress in the commissioning of the IMS seismoacoustic portion of the network and makes observations on some aspects of the event screening criteria.

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**P3.5 Analysis of Seismic, Hydroacoustic and Infrasound Monitoring Data** - Board: 18 / **P3.5-890**

# Research on Multi-Station Phase Picking, Association and Location Based on Graph Neural Networks

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In the field of seismic monitoring, the three critical tasks of phase picking, association and location are interconnected and tightly coupled. Current seismic monitoring methods typically tackle phase picking, association and location separately, and most existing phase picking methods focus on single-station waveform data processing. Graph Neural Networks (GNNs) are deep learning frameworks specifically designed to process graph-structured data. Through modeling seismic stations as graph nodes, incorporating their waveform data as node attributes, and defining inter-station geographic relationships as topological connectivity, GNNs learn graph-based knowledge to enable end-to-end multi-station phase picking, association and location. The research on multi-station phase picking, association and location based on GNNs unifies waveform feature extraction, physics-informed phase picking, phase association and event location modules together and delivers an integrated end-to-end operational pipeline for seismic monitoring.

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 27 / **P3.6-017**

# Assessment of the influence of radioxenon releases from civil nuclear activities on measured air concentrations by CTBTO IMS stations using atmospheric transport modeling (ATM)

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Monitoring atmospheric radioxenon concentration is crucial for verifying compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) and may confirm the nuclear nature of an underground explosion. The International Monitoring System (IMS) collects and analyzes air samples to determine the activity concentrations of four radioxenon nuclides (131mXe, 133mXe, 133Xe, 135Xe). Multiple civil sources, such as nuclear power plants and medical isotope production facilities, contribute to the background levels of radioxenon. This can potentially mask signals from a nuclear explosion. The understanding of the influence of known emissions on the observed radioxenon level is of crucial importance for treaty verification. This study uses ten years of IMS observation data (AUX04, AUX09, NZX46 and BRX11) to infer radioxenon source strengths from the Australian Nuclear Science and Technology Organisation (ANSTO), Nuclear Technology Products (NTP) and National Atomic Energy Commission (CNEA) medical isotope production facilities. The results of case studies are used

to demonstrate the method. The parameters of interest are maximum discharge rates, variability and uncertainty of inferred source strength and the estimate of total annual releases. The source strength of NTP is the least well known parameter so far, but it is thought to be the strongest source worldwide.

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 28 / **P3.6-049**

## Impact of Energy Calibration in X-Ray Region on Xenon Activity Concentration Calculation under Least-Squares-Based Net Area Calculation Method

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High resolution gamma spectrometry allows least-squares-based net area calculation in radioactive xenon detections. The least-squares-based calculation accounts for X-ray deconvolution and gamma peak area quantification. The International Data Centre (IDC) has been seeking a new approach to enhance the capability of gamma area quantification by taking advantage of X-ray counts. In a previous study, over 50% of discrepancies were observed when there were energy calibration shifts in the X-ray region by 2 channels, about 0.35 keV. This study investigates the sensitivity of activity concentration calculations to energy calibration. The study used six years of spike and sample spectra received at the IDC. Spikes were analyzed as the first exercise. In each spectrum, an energy calibration was performed as a reference point. Subsequently, activity concentrations were calculated while varying calibration offsets. Deviations to the reference value were examined. Depending on detected isotopes, the impact was assessed in three separate groups. Daily sample spectra with Xe-133 activity concentrations above 1 mBq/m3 were retrieved and analyzed in the same manner as in the second phase. The results strongly suggested that the activity concentration calculation is especially susceptible to the calibration shift in the X-ray region.

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**Online e-Poster Session 2** - Board: 0 / **P3.6-126**

## Caesium activity concentration at Eastern Europe IMS Particulate Stations in 2011 and the influence of meteorological parameters

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In 2011, the Fukushima nuclear disaster was a big accident and the approximate cause is the Tohoku earthquake and tsunami. In the days after the accident, radiation was released into the atmosphere and water, and caesium was detected at IMS particulate stations. Caesium (Cs) is a chemical element in the periodic table with atomic number 55 and 40 known isotopes. This study presents the activity concentrations of caesium 134, caesium 136 and caesium 137 in Eastern European stations in 2011 by collecting the data using the RN toolkit. Low and high concentration activity of caesium 134 is observed at RUP 60 (0.7197 uBq/m3) and RUP 61 (773.4387 uBq/m3), caesium 136 level reached 0.66403 uBq/m3 at RUP 60 and 55.34395 uBq/m3 at RUP 61 while caesium 137 ranges from 0.4809777 uBq/m3 to 1004.487 uBq/m3 at RUP 61 as low and high concentration activity respectively. The results of time series and caesium activity diagrams revealed the increase of caesium activity concentration in March and April. Meteorological data was used to make a correlation with different caesium ranges to display the influence of these parameters on the variation of caesium. Also, a wind rose diagram was created to reveal wind parameters at station sites.

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## Assessment of Anthropogenic Radionuclides detected by the International Monitoring System in the West African Sahelian band

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The Sahel is that band of Africa laying between 12°N and 20°N with a semi-arid region separating the Sahara desert from the Sudanian tropical savanna. The Comprehensive Nuclear-Test-Ban Treaty (CTBT) bans any testing of nuclear explosive devices which is carried out underground, in the atmosphere and underwater. Two main technologies, radionuclide and seismo-acoustic monitoring, are deployed in the International Monitoring System (IMS) used for the verification of the CTBT. In this work, we considered the activity concentrations of some anthropogenic radionuclides (Cs-137 and Cs-134) detected in the IMS from January 2024 to December 2024. The main objective is to determine the activity concentrations of anthropogenic radionuclides, classify the IMS (radionuclide) according to the radioelement mapping and establish radioactivity levels in the IMS (NEP48 and MRP43).

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# Computer Analyst: AI/ML assisted analyses of radionuclides from high resolution gamma-ray spectra

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Pacific Northwest National Laboratory (PNNL) is developing a comprehensive database of over 100,000 analyzed gamma-ray spectra from an archive from decades of radiometric analysis of a diverse range of radionuclide samples by trained gamma spectroscopists. This dataset will be leveraged to embed domain expert interpretation and analysis of gamma-ray spectra into trained semi-supervised Machine Learning (ML) tools for raw spectral data analysis and to supplement and enhance targeted deep learning techniques. ML-based algorithms have demonstrated value as a powerful tool for enhancing the precision and robustness of gamma spectroscopic analysis. However, these successes have primarily been limited to low energy resolution detectors with far less information density than high resolution detectors like HPGe employed within the International Monitoring System (IMS) network. This effort is targeted at addressing the challenges of ML overfitting and under-generalization which have resulted in poor performance in real world applications where spectral signatures vary due to detector calibration and resolution drift, varied detector/source media resulting in spectral shifts, and a resulting lack of transparency and trust in the black box approach of the decision making process when ingesting raw spectral data.

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 31 / **P3.6-347**

# Contribution of Bayesian methods and uncertainty quantification to source location and interpretation of IMS radionuclide measurements

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One of the aims of using Atmospheric Transport Modelling (ATM) in National Data Centres (NDC) is to locate the geographical areas likely to contain the source at the origin of a set of measurements at International Monitoring System (IMS) stations, and to provide an estimate of the associated release quantity. One of the main challenges lies in uncertainty quantification. For this purpose, recent studies have shown the potential of using ensemble and Bayesian methods.
In this study, we examine the contribution of FREAR (Forensic Radionuclide Event Analysis and Reconstruction, a recently available open source tool) and its Bayesian inverse modelling method to estimating source location and releases from a series of real case detections. The discussion will focus on providing lessons learnt on uncertainty quantification from an operational NDC point of view, based on comparisons to other inverse modelling methods (such as cost function and Possible Source Region) and on the use of different sets of meteorological data (including deterministic and ensemble meteorology).

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 32 / **P3.6-364**

## Interference of natural radionuclides and detector/shielding neutron interactions with the detection of CTBT-relevant radionuclides

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The CTBTO's International Data Centre (IDC) collects, processes and analyses data originating from the facilities of the CTBTO's International Monitoring System (IMS), which uses four complementary verification methods (including radionuclide) to detect nuclear explosions. Radionuclide technique is the last step to validate whether a nuclear explosion has been carried out. Data from the 73 currently operational radionuclide particulate IMS stations consist of a daily gamma ray spectrum from each station. They are sent to the IDC, where they undergo an automated analysis process. After this, the IDC radionuclide analysts refine the results during an interactive review process resulting in Reviewed Radionuclide Reports (RRRs). Several natural radionuclides, such as Pb-212 and progeny, Bi-214, Ac-228 and Pa-234m, and those induced by neutron interactions with components of the detector shielding and the detector itself, may interfere with the detection, peak identification and quantification of CTBT relevant radionuclides, such as Zn-65, Zr-95/Nb-95, Tc-99m, I-131, Cs-134 and Ba-140/La-140 (among other CTBT-relevant radionuclides). This work looks at the peak identification issues and explains what methods the IDC radionuclide analysts are applying to address these issues. It also includes lessons learned from the re-measurements of a selection of collected samples at the CTBTO radionuclide laboratories and follow-up investigations.

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 33 / **P3.6-372**

## Comprehensive Comparison of Radionuclide Laboratory Results with IMS Radionuclide Station Results

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The International Monitoring System (IMS) is a global network that when complete will consist of 16 laboratories and 321 monitoring stations providing real time data delivering insights to the nuclear explosion monitoring community. A thorough comparison of results produced by these monitoring systems and labs has been conducted utilising data from multiple years of Radionuclide Laboratory Reports (RLRs) and Reviewed Radionuclide Report (RRRs) with the aim of providing evaluation into the comparative accuracy and sensitivity of both types of facilities.

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 34 / **P3.6-394**

# Analysis of two years of data from the Swedish Radioxenon Array

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The Swedish Xenon Array is a first-of-its-kind measurement system, consisting of five SAUNA QB units placed around Sweden with an inter-distance around one order of magnitude smaller than the IMS. Here, we present a comprehensive analysis of the first two years of data (2021-2022), where xenon background sources relevant to Sweden and northern Europe are characterized, and a comparison of the source identification power (detection, location and characterization) of an array with a single, IMS-type xenon system (SEX63 in Stockholm). Among the results, we find that the array detects twice as many 131mXe/133Xe samples and 35% more 133mXe/133Xe samples, compared to SEX63. A new sample association technique based on machine learning is used to auto-detect plumes. One significant benefit of the array is that it can exclude local sources within Sweden, in contrast to SEX63. 40% of the plumes are associated with the Fleurus Isotope Production Facility (IPF). We find a clear difference in the location of potential sources depending on the isotopic composition of the plumes: many of the 133mXe detections are likely associated with nuclear facilities in Russia, while the 131mXe detections mainly originate from an IPF in Poland.

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 35 / **P3.6-550**

# (Re)Development of IDC software for particulate and HPGe noble gas analysis

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The automated particulate and HPGe noble gas analysis engine, Autosaint, has been in use at the IDC for over a decade. This code is one of the last remaining radionuclide processing algorithms written in C, with all other key applications either developed in or ported to Python 3. For long term maintainability and consistency, the functions performed by this module will be redeveloped and implemented in Python. This presentation will show the requirements, technical considerations, planned features and functions of the new analysis engine currently under development in the IDC.

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 36 / **P3.6-559**

## Radioxenon sample association using a machine learning approach

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With the establishment of radioxenon detector networks, such as the IMS, a long-standing challenge has been to accurately correlate individually detected samples that share a common source. Traditional methods, relying on classifications by human operators or simplistic time-based connections, can be time-consuming and prone to biases and oversimplifications. To address these issues, we present a machine learning-based approach designed to automate the classification and association of xenon samples across multiple stations. This approach incorporates a range of parameters, including sample strength, timing, station location and backward weather trajectories, to group observations from the same source. The model is trained using ~10,000 simulations and then applied on two years of data from the Swedish Radioxenon $Q_B$ array. Results demonstrate the model's ability to quickly classify samples, offering a scalable solution for plume identification, which is critical for pinpointing potential source sites in environmental and nuclear monitoring.

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 37 / **P3.6-625**

## Tuning alarm levels for Xenon isotope detection

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Radioxenon detection is one of the key methods used in the International Monitoring System (IMS) of CTBTO for detecting a nuclear explosion event. However, since there are numerous civilian sources of radioxenon, such as isotope production facilities and nuclear power plants, any detection of radioxenon must be carefully analysed in order to determine if the source could be a nuclear explosion.
In this work we utilize published discrimination methods based on the isotopic activity ratios of the four relevant isotopes (<sup>131m</sup>Xe, <sup>133</sup>Xe, <sup>133m</sup>Xe and <sup>135</sup>Xe) in combination with historical IMS data and simulated nuclear explosion events to tune alarm levels for different types of radioxenon detections. The in-house software framework NEMOS (Nuclear Event Monitoring Simulator) is used to simulate the full chain of nuclear explosion events, from explosion, via atmospheric transport, to detection. The goal of the tuning is to find a good trade-off that minimizes the amount of false alarms (and thus the burden of manual analysis) while still capturing true events.

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 38 / **P3.6-700**

## 20 years of Krypton-85 measurements revisited

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Bundesamt für Strahlenschutz (BfS) has been operating a network with weekly air sample collection at up to 26 locations in Germany and worldwide, with sampling going back to 1973. The samples are analyzed for Kr-85 at the BfS Noble Gas laboratory in Freiburg which is accredited according to DIN EN ISO/IEC 17025. Large quantities of the radioactive noble gas Kr-85 are released into the atmosphere as a result of reprocessing of used nuclear fuels. Reprocessing started in the 1940s mainly to separate plutonium for military purposes and the monitoring of Kr-85 has been suggested as an indicator for clandestine plutonium production. However, emissions from civil reprocessing activities have created a significant background. We analyze the data from 2005-2024 with backward ATM for more than 10000 individual samples from about 10 stations. We discuss the possibility of distinguishing different emitters using the recent shutdown of the Sellafield nuclear reprocessing plants as an example.

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 40 / **P3.6-793**

## In-core monitoring of an advanced gas-cooled nuclear reactor

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Under a collaboration known as Xenon and Environmental Radionuclide Analysis at Hartlepool (XENAH), an advanced gas-cooled nuclear reactor based in the UK has granted access to real time monitoring data of the gaseous CO2 primary coolant. These data, partly intended to inform station operators as to the state of health of the core, represent a vast repository that may be further explored for nuclear explosion monitoring. Analysis of raw spectral data performed at the UK NDC shows the presence of CTBT-relevant fission and activation products within the coolant, including radioxenons, which if released into the atmosphere may be detected by air sampling networks such as the IMS. Characterising background sources of anthropogenic radionuclides (such as nuclear reactors) is therefore an important aspect of explosion monitoring. This work presents a comprehensive analysis of the in-core Gaseous Activity Monitoring (GAM) data, discusses trends in isotopic activities and activity ratios during full power operation and outage periods, and compares the results to those expected based on reactor physics simulations.

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 41 / **P3.6-795**

## Assessing the source of anomalous caesium-137 detections across Europe in September 2024

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In early September 2024, the particulate radionuclide IMS station in Stockholm, Sweden, observed several anomalous measurements of caesium-137. Similarly unusual detections were simultaneously being observed on national monitoring networks across Europe, and preliminary investigations suggested that the source of the fission products was somewhere in Eastern Europe. In time, it became apparent that forest fires within the Chernobyl exclusion zone had resuspended a large amount of legacy material into the atmosphere. We present a joint effort between the UK NDC and the UK Met Office in performing an analysis of the event, including the use of different atmospheric transport and dispersion models (HYSPLIT and NAME) as well as source inversion tools to reconstruct release parameters such as location, magnitude and time. The results demonstrate the benefits of utilising multiple approaches, atmospheric transport models, meteorological data and radionuclide analysis techniques to characterise radiological releases such as this.

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**P3.6 Analysis of Radionuclide Monitoring Data** - Board: 39 / **P3.6-831**

## Comparison of Approaches for Memory Effect Correction and Background Measurement in a Radioxenon Detector

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Modern radioxenon detection systems exhibit a low memory effect. For example, the MIKS plastic detector cell has a memory effect coefficient of less than 5%. However, even low levels of memory effect can affect measurement results. To account for this, the gas background is measured separately and incorporated into the calculation of sample activity.

Accurate accounting for the gas background is important to ensure precise activity measurements. The standard approach, the Net Count Calculation method, applies the same region-of-interest (ROI) ratios for both the sample and the gas background.

In this study, alternative methods for gas background accounting in the calculation of radioactive xenon isotope activities were investigated. These methods provide a more accurate determination of the gas background spectra. It was found that the gas background spectrum of a selected isotope can differ from the spectrum of a sample containing the same isotope, necessitating careful consideration during activity calculations.

A series of calculations was performed based on measurements of radioactive spikes and other samples using MIKS. A comparison of different approaches was conducted, including a novel Bayesian method that incorporates a priori information about background spectra.

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 1 / **P4.1-064**

## Enhancing Seismic Monitoring Capabilities of Bogazici University Kandilli Observatory and Earthquake Research Institute Through Integrated AI Modules

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The Anatolian region, characterized by complex fault systems such as the North Anatolian Fault, East Anatolian Fault and the extensively deforming fault systems in the Aegean and Mediterranean

regions, serves as a natural laboratory for earthquake studies. These fault systems create a highly dynamic and seismically active tectonic environment. The Kandilli Observatory and Earthquake Research Institute (KOERI), responsible for maintaining high-quality seismic monitoring to issue a tsunami alert message in this region, is implementing state of the art artificial intelligence modules to enhance its operational capabilities. The monitoring system will also be extended to incorporate Global Navigation Satellite System data for early warning capabilities. We present a comprehensive upgrade to the monitoring system through the integration of specialized neural network architectures designed for phase picking, phase association and location-magnitude estimation. These AI modules are engineered to work collaboratively, forming an automated workflow that significantly improves catalog completeness and accuracy. Initial performance metrics demonstrate substantial improvements in phase picking precision, event detection capabilities and location accuracy compared to traditional methods. This modernization of the Kandilli Observatory's monitoring system represents a significant step forward in providing high-quality seismic data for the scientific community, particularly in a region of profound importance for earthquake studies.

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 2 / **P4.1-152**

## Forest fires and IMS network: A case study of wildfire outbreak in Canada in the summer of 2023

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Extreme wildfires have become more frequent and widespread in recent years, causing negative impacts on society, infrastructure, air quality, terrestrial and aquatic ecosystems. The International Monitoring System (IMS) facilities operate worldwide in remote locations, sometimes in regions regularly suffering from forest fires. This could pose a significant risk for a station's routine operation and maintenance and potentially make an IMS station vulnerable during fire season. The 2023 wildfire season was a record-breaking event in Canadian history: the total area burned exceeded 17 million hectares and was the largest recorded number in the last fifty years. In this work we will take a close look at the wildfire situation using a case study of wildfire outbreak in Canada in 2023 and examine how this situation affected the performance of some IMS stations (Yellowknife in the Northwest Territories). The study is based on statistical data published by the Canadian Interagency Forest Fire Centre (CIFFC) in the form of yearly reports (2016-2024) and data from the CTBTO IMS Reporting System and Operational Status of Certified IMS Facilities in Canada.

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 3 / **P4.1-169**

# The present technology and future challenges of the seismic monitoring used in the International Monitoring System (IMS), CTBTO

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Since the beginning of the nuclear era, the international community has debated ways to reduce the risks of nuclear weapons and their proliferation. In 1996, the Comprehensive Nuclear-Test-Ban Treaty (CTBT) was adopted by the United Nations General Assembly, with the aim of banning nuclear test explosions. The treaty obliges State Parties to refrain from conducting nuclear tests and includes an advanced verification system to ensure compliance, which is managed by the Preparatory Commission before the Treaty's entry into force. This study focuses on assessing the current technology and future challenges of seismic monitoring used in the International Monitoring System (IMS) under the CTBT. The research first provides a detailed review of the Treaty and seismic detection technologies. It explains the basic scientific principles behind various signals and outlines the detection capabilities. The process of data review and screening at the International Data Centre is also analysed. The study identifies several future challenges for seismic technology in IMS, particularly regarding evasion scenarios like decoupling (separating the test explosion from its surroundings) and mine-masking (hiding explosions in mines), which pose significant obstacles to seismic monitoring accuracy. These challenges highlight the ongoing difficulties in ensuring reliable and accurate verification of compliance with the CTBT.

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**Online e-Poster Session 1** - Board: 0 / **P4.1-206**

# Characterizing Seismic Stations' Detection Capabilities with Supervised Learning

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Accurate seismic event detection is crucial for understanding seismic activity and ensuring compliance with the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). The National Data Center (NDC) of Israel uses data from local and regional stations, as well as the International Monitoring System (IMS) of the CTBTO. With increasing seismic stations and available data, administrators have many options for selecting stations. However, stations vary in terms of proximity to noise sources, instrumentation, maintenance and the environment, all of which affect data quality and detection capabilities. To optimize station selection, it is essential to understand the strengths and weaknesses of individual stations and networks. This study aims to characterize detection capabilities and compare thresholds across different stations (e.g. deployment depth, instrumentation), regions (e.g. geology, noise proximity) and networks. Using decades of IDC bulletins, which reflect IMS detection and location algorithms and analyst expertise, we apply supervised learning to explore detection thresholds for IMS stations. Preliminary results suggest that event magnitude and station-event distance are the most influential features for detection likelihood. Station-event

azimuth also plays a significant role, indicating spatial variations in detection capabilities. These insights will help system operators select stations for monitoring and improve station maintenance where performance is lacking.

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## Empirical Evaluation of the International Monitoring Systems Detection Capability

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The primary method the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO PrepCom) uses in monitoring for underground nuclear explosions is a seismic network of 50 primary stations and 120 auxiliary stations. Currently the primary network's detection capability has been calculated using theoretical methods. But now that a majority of the network has been deployed for a number of years, we can use the empirical method developed by Schorlemmer and Woessner (2008) to determine the network's detection capability. This method relies on using the associated phases reported to the International Seismological Center from 2004 to September 2015 earthquake catalog to determine if an event at a certain distance was observed by a station. Due to the method only using final reviewed catalogs, it takes into account analyst behavior and confidence in picks. From these measurements we obtain detection probabilities for each station in the network for magnitudes of 2 to 6 and for 1 degree distance intervals to determine the probability that a station would detect an earthquake on a point on the Earth's surface. From this, we compute global detection maps for each station and then detection-probability maps for different magnitudes as well as probability-based magnitude completeness maps.

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 4 / **P4.1-282**

## Seasonal variations of the magnitude residuals at IMS three-component and array seismic stations

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Technical specifications for IMS stations require accuracy of calibration results to be within 5% and 5-degrees for amplitude and phase of the nominal response, respectively. Taking into consideration that the operating temperature for equipment components is specified between -20oC to +45oC, the sensors and dataloggers must assure operational quality within their nominal response specified and traced over the operational lifetime. However, it was noticed that ambient temperature variations may influence CALIB values acting as conversion factors to ground motion (McCormack, ECS/PRES/WGB-62/WEG/5). Despite protection measures undertaken, seasonal temperature variations at equipment vaults could reach up to tens of degrees. Therefore, such influence may impact event magnitude estimates calculated at the station. Observation of magnitude residuals (MR) at some IMS stations display seasonal variations, which could relate to temperature changes depending on sensor type, emplacement depth and vault insulation quality. The observed seasonal MR variations are found to be up to 0.25 magnitude units for mb and less prominent for Ms. If the observations are further confirmed, this may require a specification update for better vault insulation or the involvement of the IDC database CALRATIO parameter, reflecting a possible change of CALIB relative to its nominal (baseline) value based on local temperature measurements.

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 5 / **P4.1-283**

## Progress on the modernization of the IDC seismic, hydroacoustic and infrasound data processing systems

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To account for an ageing software and benefit modern computing capabilities, the International Data Centre (IDC) started a major programme ten years ago called IDC seismic, hydroacoustic and infrasound (SHI) Reengineering with the goal of creating a modernized, open-source software for SHI data processing and improving maintainability and extensibility to the system. This poster highlights recent achievements (Kubernetes computing platform, Threshold Monitoring, State of Health monitoring system…) along with ongoing efforts and challenges in the modernization of the IDC SHI software ecosystem.

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 6 / **P4.1-385**

# Identifying Misformed Events Using Classification Techniques and Likelihood-Based Model Fit Scores

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The International Data Center produces automatic event bulletins, which are subsequently verified by analysts. Analysis of 2014-2023 data shows that less than 50% of events reported in the first list (SEL1) were also included in the Late Event Bulletin (LEB). Reducing the number of misformed events could significantly ease analyst workloads. To address this, we introduce a method for assessing the legitimacy of proposed events. A key feature is whether or not the station should be expected to detect the event, which we model for each station utilizing data from the LEB. Scoring functions are then created from classifiers trained to determine whether an event from an automatic bulletin would pass an analyst's review. These classifiers use features extracted by evaluating the likelihood of the model for the proposed events and their corresponding detection patterns. A classifier based on our scoring function, applied to one year of independent SEL1 test data, was able to identify 72.05% of false events while falsely flagging just 5% of legitimate ones. Additionally, for many events with low scores retained by the analysts, the scores provided valuable insights and pointed to important data corrections. These events had much higher scores in the LEB.

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 8 / **P4.1-519**

# Interactive event detection assessment of the International Monitoring System

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Hourly maps with the average and worst-case event detection capability of the seismic component of the CTBTO's International Monitoring System have, for many years, been accessible via CTBTO's secure web portal. The basis for these maps is estimates calculated by the Threshold Monitoring method, which has been part of CTBTO's processing pipeline since the establishment of the International Data Centre. To utilize the full potential of the Threshold Monitoring data accumulated in the processing pipeline, NORSAR has developed software to interactively explore the data in a flexible manner. With support from the International Data Centre staff, a new web interface is made available to CTBT States Signatories where the event detection capability can be displayed and analysed for any user-selected time interval and geographical region. This is particularly useful as the event detection capability can vary significantly with time during situations such as high station noise

levels, large earthquakes, or outages of key stations. In this e-poster we illustrate the functionality of the new tool and show results for different real scenarios.

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 9 / **P4.1-637**

## Data Quality Assessment for Five BMKG Stations Included in the CTBTO International Monitoring System

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Data quality assessments for five BMKG stations (PSI, LEM, BATI, SIJI, and JAY) which included as auxiliary stations in the CTBTO International Monitoring System have been conducted. The Probabilistic Power Spectral Density (PPSD) analysis was applied to determine the level of background noise around the sites to assess the reliability of sensor placements for seismic monitoring. Meanwhile, the data quality is assessed by identifying sensor misorientation to ensure that the seismometer is installed correctly. We analysed the PPSD using a 10-day three-component continuous waveform, and the results suggest that the background noise from five stations does not exceed the global noise threshold from Peterson (1993), with PSI having the lowest noise level and LEM having a relatively high level of cultural noise. Sensor orientation measurements show that PSI and BATI are misaligned by approximately 16 degrees, while SIJI, JAY, and LEM are oriented within 5 degrees of true north. This assessment indicates that these five stations remain able to be used for natural and artificial seismic monitoring. Data quality monitoring should be performed on a regular basis to verify that the sensors are in good enough condition to produce accurate data for further analysis.

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 7 / **P4.1-666**

## Towards a modern and robust quality control tool based on DTK-QUALITY data

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Noise levels at a waveform station can be analysed by computing Power Spectral Density (PSD), which is an important quality indicator for waveform data recorded by the International Monitoring System (IMS) seismic, hydroacoustic and infrasound network. The continuous monitoring of the PSDs as part of the quality control process ensures that the IMS network is operating efficiently, and that instrument malfunctions or data quality issues can be detected and addressed in a timely manner. Currently at the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), the PSD data is computed using different tools and is exposed to several challenges, including obsolescence, maintainability, homogenization, reproducibility, and usability. The CTBTO explores solutions to reduce the number of applications by having one single library that could be used in different applications dedicated to performing station quality control, certification or revalidation of the IMS station, or assess and evaluate network performance. The CTBTO evaluates the DTK-QUALITY software (developed and maintained by French National Data Centre), which is a feature-rich and configurable command-line tool. This presents a promising opportunity to overcome existing challenges and to advance the quality control process for the benefit of the International Data Centre, IMS and authorized users (NDCs through NDC in a Box and station operators).

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 11 / **P4.1-720**

## Scaling up the ATM Pipeline: Boosting Performance and Efficiency

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The Atmospheric Transport Modelling (ATM) pipeline is essential for linking radionuclide measurements from the International Monitoring System (IMS) to potential source locations. Operated by the Comprehensive Nuclear-Test-Ban Treaty Organization's International Data Centre (CTBTO-IDC), it has been fully functional for many years. Despite its effectiveness, several components need refinement to meet the Provisional Technical Secretariat's (PTS) standards, for example, through automated CI/CD with GitLab. As a computationally intensive segment of IDC data analysis, ATM executes hundreds of simulations daily. Key objectives include, for example, reducing current meteorological file sizes to facilitate ensemble modelling and high resolution applications, boosting computational efficiency for greater simulation throughput, expediting the delivery timeline of final products on our platform, and upgrading the ATM model version. This presentation will showcase the present status of the ATM pipeline alongside a detailed roadmap outlining planned enhancements over the coming years aimed at aligning with PTS standards and ensuring scalable performance improvements.

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 12 / **P4.1-745**

# The Five M's of Seismic Station Quality: Machines, Methods, Metadata, Monitoring, Maintenance

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For data generated by seismic monitoring networks to be useful and trustworthy, they must be sufficiently accurate and precise. While it is necessary that seismic instruments comprising networks be appropriately accurate and precise, that is not sufficient, as there are additional factors that determine seismic station accuracy. To help network operators compile and manage a set of necessary and sufficient conditions for seismic station quality, we advance five categories for station operators to consider, along with a useful mnemonic device: the "Five M's": Machines, Methods, Metadata, Monitoring, and Maintenance. "Machines" refers to the instruments, "Methods" to how instruments are deployed and installed, "Metadata" to the critical importance of documenting the nature of the data so it can be properly interpreted, "Monitoring" to the need to regularly inspect the station quality, and "Maintenance" to the need to keep the station in proper running order. We introduce and define all five categories, and elaborate on the first three in more depth. "Machine" quality touches on instrument accuracy, precision, calibration, and certification. We elaborate on the nature of proper installation and operation "Methods", and review the relevance and methods for creating and managing station "Metadata".

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 13 / **P4.1-856**

# A comparison of IDC Reviewed Event Bulletins with a baseline from the results of the 2024 Experiment

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The 2024 Experiment, conducted from 16 to 27 September 2024, focused on the production of automatic and analysts generated products. During the experiment, the International Data Centre (IDC) generated a series of Reviewed Event Bulletins (REBs). To ensure an objective comparison, three randomly selected REBs were compared against a baseline bulletin created by an experienced team. The comparison was conducted using two validated software tools: BulCmp and BullComp, both designed for robust event matching and statistical assessment. Key metrics such as matched events,

missed events, extra events and error ellipse overlap were computed, emphasizing classification accuracy through precision and recall calculations. This poster will outline the experimental design, detail the methodologies employed for quality assessment and summarize the key findings.

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## Radionuclide IMS Network QA/QC programme

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The Provisional Technical Secretariat (PTS) runs a radionuclide network QA/QC programme for samples measured by the International Monitoring System (IMS) radionuclide particulate stations on a periodic and continuous basis. The purpose of the radionuclide network QA/QC programme is to verify station performance (by ensuring that produced data are of acceptable quality, the station poses requested sample handling and shipment capability and that the station is working within its certified operational specifications), to initiate corrective actions if non-conformities are found and to take preventive actions to avoid possible non-conformities. To check the performance of a station, a randomly selected sample (Manual, RASA and Cinderella) is dispatched every quarter from the station to a radionuclide laboratory. The obtained results are compared by the PTS using a 7Be metric. The evaluation criteria are based on the percentage difference (%D) between radionuclide laboratory and radionuclide station results and zeta (ζ) score of the two results according to the ISO 13528 requirements. A global overview of the radionuclide network QA/QC programme during the 2020-2024 period is presented in this paper, with the emphasis on actions taken following the comparison of results between radionuclide laboratories and stations.

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**P4.1 Performance Evaluation of the International Monitoring System** - Board: 15 / **P4.1-874**

## Evaluating Cs-137 Analytical Variations in IMS network particulate samples: Insights from Ten Years of IDC and Radionuclide Laboratories Results

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The International Monitoring System (IMS) is a unique global network designed to monitor compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Complementary to three waveform technologies, the 80-station radionuclide network provides continuous worldwide monitoring. This radionuclide network is further supported by 16 specialized laboratories, which offer independent expert analysis of IMS samples upon request. This work presents a comparative assessment of Cs-137 analysis results performed by the International Data Centre (IDC) and Provisional Technical Secretariat-certified radionuclide laboratories over the past decade. Cs-137 was selected for its relevance to monitoring, its long half-life (thus mitigating decay-related uncertainties), and because initial difference tests obtained from the data evaluation revealed notable discrepancies. Using both difference tests and zeta scores, potential causes of these inconsistencies, including peak interference, baseline underestimation, and background subtraction methods were investigated. The obtained results underscore the need for ongoing analytical refinements to ensure reliable radionuclide measurements in support of effective verification activities.

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**Online e-Poster Session 2** - Board: 0 / **P4.2-048**

# Photovoltaic Energy Storage System Solution to Inspection Team

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For the most practical cases, the inspection team should be self-sufficient in the inspection area. From the energy requirement perspective, the inspectors need energy for their daily accommodation support. There are different categories of on-site inspection (OSI) equipment, more than 100 tonnes, which need electricity supply for normal functionality. This work provided a photovoltaic energy storage system solution to the inspection team. As a customized transportable solar ground power station it can realize rapid deployment and installation with lightweight and flexible photovoltaic modules. It utilizes LiFeO4 cells, which are safer with a higher energy ratio of up to 175 Wh/kg. One 7-meter-sized energy storage container has the maximum output power of 200kW/400kWh/CNTR. The system could provide continuous power support for off-grid areas quickly, with the working temperature as low as -40℃. During the day, the energy storage system would be charged by sunlight; at night, it would charge the OSI equipment for use the next day. Photovoltaic energy is also a kind of green energy. Its application to the OSI mission is also in line with the United Nations Sustainable Development Goals.

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**P4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 18 / **P4.2-107**

# NDC Costa Rica and GCI-Link for Latin American data recovery for the IDC

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In recent years, OVSICORI-UNA has made a significant investment in communication, storage and data protection technology, such as intelligent storage systems with deduplication and real time backup. Through this implementation and a redundant link, we ensure that the data from our auxiliary station AS25 is well protected, with almost zero data loss. The previous data protection capacity is because we do not depend exclusively on communication with the VSAT, as is the case with the CTBTO. Due to the above, the possibility of developing a protocol for data recovery for the International Data Centre through the use of our GCI-Link. As well as the assessment of a data transmission hub for the region (Latin America).

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**P4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 35 / **P4.2-199**

# Virtual GCI for NDC (VPN Docker)

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To secure data delivery to National Data Centres (NDC) with cloud infrastructures, a new communication method was developed to address this growing demand. This solution utilizes Linux Docker containers running programmable VPN clients, offering a highly flexible approach to deployment. VPN Docker can be deployed within minutes on any Linux-based software or hardware platform, ensuring the implementation of the latest security standards. Additionally, the system includes automated monitoring, alerting and a unique disaster recovery concept, providing a comprehensive ecosystem for secure communication. This approach offers multiple significant advantages. It can be deployed across hardware, software or a combination of both, and is compatible with any internet connection. Deployment times are significantly reduced from months to minutes, and the solution effectively addresses challenges related to embargoes. It can support multiple NDCs within a single country and provide programmable monitoring and alerting features, simplifying infrastructure management. Finally, migrations and decommissioning can be completed within minutes, while the solution also offers programmable disaster recovery at a low cost. In summary, this innovative solution enables the secure transmission of data and products to NDCs without the need for physical networking equipment, streamlining the communication process while maintaining robust security standards.

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**P4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 19 / **P4.2-236**

# EU Donation to Upgrade the ASF056 Auxiliary Station Borehole Seismometer

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The ASF056 auxiliary station borehole seismometer was malfunctioning, and the local operator in the State Party lacked the financial resources to cover the costs of replacing and upgrading the outdated equipment. Through the efforts of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) and the Jordan Permanent Mission, the European Union (EU) provided a significant donation to support the replacement and upgrade of the ASF056 station seismometer. Borehole seismometers are a critical tool for detecting seismic events with high precision, and this upgrade will enable more accurate analysis of local seismic activity and the International Monitoring System. The mission was executed by the ASF station operators, the CTBTO team and technicians from the seismometer manufacturing company. The objectives of the mission were as follows: a. Recover and decommission the existing Guralp equipment (borehole seismometer and digitizer), completed by the Jordan Seismological Observatory staff; b. Deploy nanometrics equipment from SO59480, including the Trillium 120 Borehole Seismometer (T120-BH2-2000), Centaur Digital Recorder CTR4-3A, GPS antenna and vault tamper switch; c. Perform borehole sensor orientation analysis using a reference sensor.

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**P4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 20 / **P4.2-306**

# Design and Implementation of Multi-Redundant Seismic Data Transmission with VSAT and GSM

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The Meteorology, Climatology, and Geophysics Agency (BMKG) is an agency that has an obligation to present earthquake data to the people of Indonesia. The earthquake data presented is obtained from 507 earthquake sensor sites spread throughout Indonesia. Earthquake data from all sensor sites is sent to servers located at the BMKG Center in Jakarta and the BMKG in Bali. Data transmission is carried out using an intranet network with a local IP address through VSAT communication and using the VPN protocol as an intermediary to access the internet network when using GSM communication. From experience, there are sometimes interruptions in both GSM and VSAT communication modes so that data cannot be sent to the server. To eliminate risks and improve data

quality in terms of reliability and data availability, a multi-redundant communication system is designed to send seismic data to the server using VSAT and GSM communication at seismic sensor sites that have been covered by GSM cellular signals.

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**P4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 21 / **P4.2-318**

## Preliminary Design of Deep Learning-Based Link Quality Estimation Using Signal to Interference and Noise Ratio (LQE-SINR) for GSM Communication in Indonesia's Seismic Network

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A total of 332 seismic stations operated by the Meteorology, Climatology, and Geophysics Agency (BMKG) utilize Global System for Mobile Communication (GSM) to transmit seismic data. Stable communication ensures the quality of transmission and the availability of seismic station data. Link Quality Estimation (LQE) can measure link quality based on physical metrics, thereby improving network stability by selecting communication links before they become unstable. This study proposes an LQE-SINR design with a temporal feature extraction concept from SINR data. The simulation is conducted on ten seismic stations located on Java Island. The design is built using data sets recorded under the environmental conditions of seismic stations, employing RNN, LSTM, GRU and BiLSTM algorithms. The RNN model demonstrated the best performance with an RMSE of 0.71 and MAE of 0.56 at site GEJI, while LSTM performed best with an RMSE of 2.21 and MAE of 1.33 at site MLJI. The GRU model excelled at site CSJI with an RMSE of 2.35 and MAE of 1.56, while BiLSTM achieved the best results at site PRJI with an RMSE of 1.43 and MAE of 1.08. Overall, each seismic site exhibited different SINR patterns, but the RNN model showed the best performance across most sites.

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## Perspective for SPALAX-NG improvement

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In the context of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), the CEA/DAM developed the SPALAX-NG (Système de Prélèvement Automatique en Ligne avec l'Analyse du Xénon – New Generation) certified in 2021. From this date, it was introduced in the International Monitoring System to detect xenon releases following a nuclear explosion. This system is still under continuous improvement. In particular, CEA/DAM continues to work on several aspects (detection, materials, heating components ...) to improve its operational and technical robustness. This presentation aims to provide an overview of the different ways in which the SPALAX-NG technologies can be improved.

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**P4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 23 / **P4.2-418**

## Design of standardized turnkey power cabinet for remote stations

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Building on its extensive experience in providing turnkey power solutions for remote scientific stations, Enviroearth has focused on improving its solutions by developing a new, standardized solar-powered power cabinet for stations with low power requirements. It addresses the challenges faced by remote locations, where reliable, sustainable energy sources are critical. Initially designed for solar input, the power cabinet can be adapted for other energy sources. It offers a standardized, yet modular solution while ensuring uninterrupted power supply for monitoring stations. The design process incorporates both field tested knowledge and proprietary research and development, allowing for customization based on specific station needs and environmental conditions. The goal of this development is to provide a robust, adaptable and efficient power solution for International Monitoring System stations in remote locations.

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## Relation About Lightening – Electricity and Monitoring Systems

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The present project has the purpose of describing the design and developing many systems protections against lightning through the analysis of the ground resistivity and the application of the standards of IEC 62305, in order to solve problems that are produced through the impact of an atmospheric discharge in the telecommunications nodes.
The design will be made primarily from the analysis of the ground resistivity using the "Wenner" method. Through experiences and data obtained in the field, the different factors that can affect the risk of heritage loss and the risk of human life loss, for which the design of the system of protection and the ground system has a direct relation, will also be considered. Also, the ground analysis is important to make prospections through the ground, related to the electricity, using mathematical methods as "Schlumberger", with the main objective to characterize the layers inside the ground, or to find water or find caves. Nowadays, it is possible to relate the geoelectric and lightning, with the response of seismic instrumentation installed on a monitoring system, this purpose has the objective to learn about the relation to electricity and the ground.

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**P4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 25 / **P4.2-461**

## Upgraded Puerto La Cruz Seismic Station (PCRV) 2023-2024: Boosting Global Seismic Monitoring and Nuclear Test Verification

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The modernization of the Puerto La Cruz seismic station (PCRV), carried out in 2023 thanks to the support of the European Union Fund and the Provisional Technical Secretariat, has significantly increased the availability of high quality seismic data at the International Data Centre and the National Data Centre. This improvement has reinforced global seismic monitoring networks, enabling more accurate detection in the Caribbean and South America of seismic and non-tectonic events such as nuclear tests. The high quality data transmitted from PCRV contributes to the verification of the Comprehensive Nuclear-Test-Ban Treaty by enabling more robust detection of seismic signals associated with underground nuclear explosions and other events. Additionally, this data is fundamental for scientific research, seismic risk assessment and the development of hazard maps. The station increased its operational availability by working 24 hours a day, all year, positioning PCRV as a reference in regional and global seismic monitoring. This work demonstrates the highly valuable comparative results obtained before and after the hybrid system upgrade, which are of great interest to international monitoring engineering systems

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**P4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 27 / **P4.2-572**

# IMS stations backup power: Transition to lithium batteries technology

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Lithium batteries are constantly evolving. Their applications are diverse and varied, ranging from small portable electronic devices to large energy storage. These batteries offer the best specific energy (capacity/weight ratio) on the market, have a longer lifespan and can have high depths of discharge. They operate in extreme environments. This makes them ideal for International Monitoring System (IMS) sites which have difficult access, or have off-grid or unreliable power supplies. However, some of the less positive aspects of this technology are often overlooked. In addition to the environmental impact (mining and pre-treatment processes, and limited recycling of batteries thereafter), their energy-intensive manufacturing process is one of the reasons for their sometimes exorbitant prices. Their transport also requires special precautions (strict regulations). Using lithium batteries outside the manufacturer's specifications will shorten their service life and, in the worst cases, may lead to fire or explosion. To optimize such an investment and benefit from its advantages, the IMS needs to carry out preliminary engineering studies for each site before installation, install and configure high-performance battery management systems and train station operators for the monitoring and maintenance.

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# Smart Dust based on Quantum Artificial Intelligence System for Urban Safety Against Nuclear Detection

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Harnessing nanotechnology, smart dust is revolutionizing nuclear detection and urban safety. These sub-millimeter autonomous sensors detect radiation, toxins, temperature and vibrations, integrating with IoT and machine learning for real time monitoring and predictive analytics. Quantum based AI further enhances its detection capabilities, making smart dust a vital tool in security. Smart dust enhances on-site inspection operations, enabling precise mapping of radioactive particles, chemical signatures and seismic activity while reducing reliance on human power. It continuously monitors air quality, radiation levels and toxic substances, providing real time alerts for inspector safety. For urban security, integrating smart dust with quantum AI improves radiation anomaly detection and crisis management. Autonomous deployment in key infrastructure enhances monitoring, while quantum based AI processes large data sets for real time threat analysis. Future developments may enable smart dust to absorb radiation, offering long term protection against nuclear threats. This paper explores smart dust applications in nuclear security, containment and surveillance, material control and accountability and urban safety. It highlights its potential use by the Comprehensive Nuclear-Test-Ban Treaty Organization in on-site inspections, inspector safety and seismic/acoustic monitoring. Smart dust's autonomous operation and wireless transmission offer cost effective solutions for nuclear safeguards.

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**P4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 29 / **P4.2-612**

# BMKG VSAT Network Disaster Recovery Plan as Efforts to Optimize Data and Sending Information for Meteorology, Climatology and Geophysics

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The Meteorology, Climatology and Geophysics Agency (BMKG) is a government agency that has the task of providing data and information services for meteorology, climatology and geophysics as well as delivering information to the public and related agencies. BMKG empowers and relies on the VSAT network, which works 24 hours, 7 days a week. The BMKG VSAT communication network is a system that connects all systems within the integrated BMKG environment and requires a real time data exchange process. The public is increasingly critical in demanding that BMKG information be obtained more quickly, precisely, accurately, easily understood and can reach all corners of the country. The paralysis of the VSAT network in the BMKG environment is critical because it can cause communication paralysis both internally and externally at BMKG. Therefore, the development of the BMKG must be carried out in an integrated manner accompanied by back-up (disaster recovery) so that the dissemination of weather information and disaster events for the community is not disrupted. Data collection was carried out by conducting literature studies, conducting interviews with users and administrators of BMKG assets, observing BMKG assets and studying organizational documents. The results of this study are DRP documents that are adjusted to the BMKG duties and functions.

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**P4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 30 / **P4.2-618**

# A Modular Approach to the New Integrated On-Site Inspections Field Laboratory Layout

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In preparation for the Integrated Field Exercise (IFE) and based on lessons learned from the past field exercises, the equipment and implementation section of the On-site Inspection (OSI) Division of the Provisional Technical Secretariat has entered into an advanced stage of OSI support and deployment infrastructure integration. The OSI field laboratory deployment and operational layouts

were redesigned between 2023 and 2024 to keep abreast with the current OSI deployment infrastructure enhancements. This poster illustrates a hybrid integration option based on new field laboratory tent modules, the SAUNA laboratory in a flight POD and radionuclide laboratory detection capability deployed in a 20ft container. The hybrid field laboratory configuration was validated during the recent IFE preparatory training in December 2024 and is ready for deployment at the incoming IFE. This layout is an important milestone for the development of the final modular radionuclide laboratory concept, which will be rolled out after the IFE based on IFE lessons learned and follow-up recommendations.

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**P4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 31 / **P4.2-655**

## NORSAR AS72/SPITS Power system upgrade and plans for Antarctic off-grid station

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NORSAR is the Norwegian National Data Centre (NDC) and operates six stations of the International Monitoring System. These are the primary seismic arrays NOA/PS27, ARCES/PS28, the auxiliary seismic array SPITS/AS72, the auxiliary single seismic station JMIC/AS73, the infrasound array IS37 and the radionuclide station RN49. It is crucial to have a stable power supply with a sufficient battery bank capacity to the stations. The auxiliary station AS72/SPITS was refurbished to secure stable operation for the future in 2022. This presentation will give an overview of the first years of operating the new power system with lessons learned, changes and expansions. Transition from project to daily operation and scheduled maintenance. The lessons learned from the AS72 power system upgrade will be leveraged in a research project at the Norwegian Antarctic station Troll where NORSAR is planning to establish a seismoacoustic 9-element off-grid array station. This presentation will outline the initial planning of the project and design choices.

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**P4.2 Systems Engineering for International Monitoring System and On-Site Inspection** - Board: 32 / **P4.2-698**

## New Infrasound Monitoring Capabilities in Sweden

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Infrasound sensors have been installed for national purposes at the site of the Hagfors seismic array in Sweden. The co-location of the infrasound sensors with the central elements of the International Monitoring System (IMS) auxiliary station (AS101) facilitated straightforward deployment by leveraging the existing infrastructure. Acoustic inlets were designed and produced in-house using AI-driven 3-D printing technologies, then integrated with ISO-standard components (water and air pipes, hoses and fittings), simplifying maintenance and ensuring a cost-effective installation. The addition of acoustic sensors in Hagfors strengthens the national ability to detect and analyse both natural and human-made events across seismic and infrasound domains. This contribution presents the new operational infrasound array, demonstrates the integration with the seismic system and explores its capabilities to detect various natural and anthropogenic infrasound sources.

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# Upgrade of the Swedish auxiliary seismic array AS101 in Hagfors

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Since the 1960s, the Swedish Defence Research Agency (FOI) and its predecessor organizations have conducted seismological measurements in the Swedish region of Värmland. Established in 2001, the Hagfors station (HFS) serves as an auxiliary seismic array within the International Monitoring System (IMS) network. In 2021, the station underwent significant upgrades, including the installation of new instrumentation from Güralp, including 3T-120 seismometers and Affinity data acquisition hardware. We have also started a survey of the electrical installation and lightning protection at the station. We present the status of the station, highlighting the experience gained in addressing new challenges and upgrading legacy equipment.

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# Latest major upgrades at the IMS seismic stations

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The Comprehensive Nuclear-Test-Ban (CTBT) International Monitoring System (IMS) network comprises two global seismic networks: a primary, based on 50 stations, and an auxiliary, based on 120 stations. Both networks undergo ageing and obsolescence, as the equipment is reaching more than 20 years of operation in the field and, in some cases, is no longer supported by equipment providers. Keeping the network operating efficiently and continuously meeting the minimum requirements specified in the draft IMS Operational Manual for seismic technology is of paramount importance to ensure uninterrupted, high level performance and adequate sustainment of the IMS network. This work presents three examples of major recapitalization activities performed both at primary and auxiliary seismic stations: the primary seismic array PS40, based on 20 elements, and requiring major actions on equipment and power, the relocation of the seismic 3-component station PS34 and the major structural and instrumentation upgrade of the auxiliary seismic array AS57.

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**P4.3 Use of enabling Information Technologies** - Board: 36 / **P4.3-381**

# Feasibility Study of Internet Paths and Communication Methods in Seismic Networks in Indonesia for Earthquake Early Warning (Case Study of the Western Region of Java Island)

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The implementation of Internet of Things (IoT) based Earthquake Early Warning Systems (EEWS) in Indonesia faces challenges in the efficiency of data communication lines to ensure real time earthquake detection. Currently used internet lines include VSAT private network, public GSM 4G, and GSM 4G leased line, with varying performance in terms of connection speed and stability. In addition, communication protocols such as SeedLink and Nanometrics Protocol are used in real time data transmission to support monitoring continuity. We aim to analyse the feasibility of VSAT, GSM, and leased line based internet lines and evaluate the effectiveness of data transmission protocols based on latency parameters, data completeness, and real time monitoring capabilities, with a case study in the western region of Java Island, which has a high level of earthquake vulnerability. The results show that the GSM 4G leased line with a private network provides the best performance in terms of latency and data completeness, while the Nanometrics Protocol with the Centaur digitizer produces adequate latency through an increase in the data compression factor. These findings provide strategic guidance for selecting the optimal communication path and protocol, thereby improving the speed, accuracy and reliability of the EEWS system in detecting earthquakes in vulnerable areas of Indonesia.

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## Implementing Observability for the Secure Web Portal

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This paper explores the strategic implementation of the Elastic Stack (ELK) for enhancing observability and logging capabilities within the Secure Web Portal (SWP). The ELK stack, comprising Elasticsearch, Logstash, and Kibana, was integrated within SWP to create a comprehensive logging system. By connecting all application logs to a central Syslog instance, data was stored in Elasticsearch. This approach facilitated the aggregation and analysis of logs from multiple components, providing real time insights into the system's operational status. Elasticsearch itself functions as a powerful search engine and analytics tool, using a unique data store optimized for real time indexing and full-text search. This project demonstrates how observability, achieved through the ELK stack, can significantly enhance the performance and resilience of the SWP. The ability to measure a system's internal states by looking at its outputs enabled faster resolution when issues occurred. In conclusion, applied observability, using the ELK stack, offers a significant advantage for securing and managing complex systems, aligning with the trend of using AI to analyse and optimize data use. The system was designed to monitor data flows, schedules, and dependencies, incorporating key dimensions of data observability, including freshness, quality, volume, schema and origin.

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**P4.3 Use of enabling Information Technologies** - Board: 38 / **P4.3-399**

## Secure Web Portal (SWP) and Elasticsearch Integration for Enhanced Data Access.

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This paper details the integration of Elasticsearch into the Secure Web Portal (SWP), a platform that States Signatories use to access vital resources related to the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The previous SWP system, which relied on a traditional relational database (Oracle), faced some limitations with performance, scalability and data access. To address these challenges, Elasticsearch, a distributed search and analytics engine, was incorporated into the SWP. This integration significantly enhances the system's ability to quickly retrieve historical data, provides a more user friendly search and visualization interface, and ensures the system can scale to handle increasing loads. The Elasticsearch integration has led to improved data availability and retrieval speed,

real time dashboarding capabilities, enhanced system observability, and creates opportunities for future innovation. Future development areas include optimizing the Elasticsearch setup, expanding the use of the Experts Communication System, improving observability, integrating real time data streaming, adopting machine learning, and providing user training. This project provides a more modern and efficient way to access critical data, setting the stage for more advanced data analysis techniques.

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**P4.3 Use of enabling Information Technologies** - Board: 39 / **P4.3-483**

## AI-Driven Detection of Malicious Codes when Integrating Data from Monitoring Technologies

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Integrating data from various monitoring technologies has become essential to detect and mitigate the spread of malicious code in modern digital ecosystems. However, the heterogeneity and complexity of data sources present significant challenges to ensure smooth and accurate detection. This paper presents an AI-based framework for detecting malicious code that leverages a deep learning approach to analyse and correlate data from various monitoring technologies, including network traffic analyzers, endpoint detection and application logs. The proposed system uses advanced feature extraction and fusion methods to unify disparate data streams into a coherent data set, enabling the identification of complex attack patterns that are often missed by traditional detection methods. Experimental evaluations demonstrate the framework's ability to improve detection accuracy, reduce false positives and adapt to evolving threats in real time. This work highlights the potential of AI to improve cybersecurity by providing a robust and scalable approach to detecting malicious code on multi-source monitoring platforms.

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**P4.3 Use of enabling Information Technologies** - Board: 40 / **P4.3-536**

## Disaster Recovery in the CTBTO

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) operates the International Monitoring System (IMS), a global network of 306 certified facilities, comprising seismic, hydroacoustic,

infrasound, and radionuclide technologies, transmit data to the International Data Centre (IDC) via the Global Communication Infrastructure (GCI). The IMS is essential for detecting and verifying nuclear test explosions, underpinning international security. A catastrophic disaster could result in the partial or total loss of the CTBTO's primary computer center (PRI) at the Vienna International Centre, significantly impacting the IDC's ability to fulfill its operational requirements of providing timely data and products to States Signatories. To address this critical vulnerability, the CTBTO is exploring disaster recovery strategies, including the development of an alternative backup site (ALT) capable of sustaining IDC operations during a disaster. A two-month pilot study was conducted to test the use of an ALT for receiving and disseminating IMS data. It provides insights into the CTBTO's required measures to mitigate risks, ensure operational continuity, and preserve the integrity of global nuclear-test monitoring. The outcomes of this initiative will strengthen the resilience of the IMS and the IDC against future disasters and provide guidance on the phased approach for the implementation of an ALT.

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## Evaluating AI Code Assistants for Enhanced Software Development in CTBTO: A Modular Approach

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The increasing complexity of software development in the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) necessitates the adoption of innovative tools and techniques to enhance productivity and efficiency. LLM-based AI code assistants have emerged as a promising solution, offering capabilities such as autocomplete, code refactoring, error detection and correction, chat based question answering, and context-aware suggestions. However, evaluating the effectiveness of these AI-powered tools in the CTBTO context is crucial to ensure their reliability, security, and compliance with organizational standards. In this work we present the results of the evaluation of open source AI code assistants in CTBTO, focusing on a modular approach that incorporates multiple components, including autocomplete models, chat models, local and remote context engines, filtering mechanisms, and training engines. We will explore the trade-offs between model size, latency, and suggestion quality, as well as the importance of integrating these components with existing toolchains and software development lifecycle data. By adopting a modular approach to AI code assistant evaluation, the CTBTO can minimize vendor lock-in, stay up to date with rapid advancements in AI, and tailor solutions to specific organizational needs.

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## A new system for data acquisition and storage in Kazakhstan's National Data Centre

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During 2024-2025, a state of the art data collection and storage system was created at the Kazakhstan National Data Centre. The system is designed to reliably store all information received by the Data Centre and provide this information for further processing and scientific analysis. Data sources for the created system are data received both in real time and any archive data from various sources and in various formats. The main formats of seismic data entered into the system are CSS3.0 and miniseed, but there is a possibility of significant expansion of this list. The system allows saving data obtained from sources such as - file system (simple data files), Seedlink-server data, and queries to FDSN web services. In addition, the system is capable of querying and storing metadata and response information for all seismic data. If necessary, it is possible to generate metadata and response files based on seismic equipment data, and based on the database (IRIS DMC Library of Nominal Responses for Seismic Instruments). The main programming language used to create this system is Python, and the framework for seismic data processing is Obspy 1.4.1. PostgreSQL 17 is used as DBMS.

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## CDStreamer: An asynchronous Transceiver Continuous Data (CD) approach for SHI raw data distribution

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In this research, we will present our recent developments of using streaming platforms in Continuous Data (CD) distribution. This research aims to utilize an asynchronous and loosely connected framework between senders and receivers for the transfer of the continuous raw data of the seismic, hydro-acoustic and infrasound (SHI) stations. We will demonstrate the implementation using various types of message brokers, including RabbitMQ, Kafka and Apache Pulsar. Also, the received data will be stored in a SQLite searchable, daily, file-based, serverless, zero-configuration and transactional SQL database engine. Additionally, data storage and indexing solutions, such as PostgreSQL, Oracle, or Elasticsearch, will be investigated and explored to enhance the comparison and provide a broader perspective. Furthermore, the advantages and disadvantages of the proposed work will be discussed. Finally, a detailed comparison between the message brokers used will be presented.

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## Challenges of building a cost-effective, resilient and secure network in Today's world - Use case: The GCI IV

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The Global Communications Infrastructure (GCI) network is how the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization fulfills its responsibilities related to receiving and distributing data and reporting products to the verification of the Treaty [Article IV. Verification, Section A, Paragraph 14 (a)]. Since it started in 1998, this network has evolved and is currently operating its 3rd generation and is preparing to transition to the 4th generation by 2028. This network of 600+ links, deployed in 100+ countries including the polar and Antarctic regions, requires tremendous effort and resources to be operated and maintained. Additionally, the growing demand in network throughput, the variety of connectivity requested, environmental and climate challenges, the surge of emerging technologies such as Low Earth Orbit satellites, artificial intelligence, blockchains, quantum computing and algorithms, and many more, poses serious challenges to the development of a coherent and modern network architecture for the 4th generation GCI, considering all these changes. Based on all the above, a mapping of the various challenges identified to the risk and threats they pose to the future GCI network, and to the opportunities that can be leveraged from several emerging technologies is proposed.

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## Advancing Decision Making and Sustainment of Seismic and Infrasound IMS Network: From a Data-Driven Methodology to Network Summary in The Multi-Technology Integration Portal (MuTIP)

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The rapid evolution of information technology has revolutionized traditional ways of working and helped to create tools to support the technical divisions of the Commission in their activities. By benefiting from it, a data-driven software tool "Network Summary in The Multi-Technology Integration Portal (MuTIP)", is being developed to streamline International Monitoring System (IMS) sustainment decision making. The tool retrieves data from various sources, transforms it and models it, and then presents it to the end users. The visualization of the data shows a projection of the seismic and infrasound IMS network status for the upcoming 20 years. This data-focused approach and visualization serve to identify pain points and potential issues and help to prioritize the work that needs to be done on the IMS stations, and thus contribute to protecting and sustaining the unique global alarm system that plays a crucial role in global peace and security.

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## Enhancing Information Access to CTBTO Staff through Generative AI: A Smart Chat Application for Simplified Access to Complex Directives and Protocols

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) utilizes and oversees daily processes through a rigorous framework, relying on extensive procedural manuals, protocols, and regulatory guidelines. Accessing and interpreting these complex documents can be time consuming and require deep domain expertise, creating challenges for staff members across various operational and scientific functions. To address this, we present a Generative AI-powered chat application designed to enhance information accessibility for CTBTO personnel. The application enables users to ask detailed questions in natural language and receive structured, contextually relevant responses, with direct references to official documentation for verification. This tool allows for to quick retrieval of critical information and improves efficiency in decision making, training, and operational workflows. To ensure accuracy and reliability, the system is utilizing the most efficient pre-trained Large Language Model (LLM), which has been provided with comprehensive CTBTO documentation from a specific domain. The LLM is configured to strictly adhere to these verified sources, ensuring that responses are derived solely from the provided materials. If the requested information is not available in the documentation, the system explicitly states that it does not have an answer rather than generating speculative responses.
This study highlights the infrastructure configuration, application architecture, usability cases and analytics monitoring system, alongside ongoing development efforts and key challenges.

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**P4.4 International Monitoring System Sustainment into the future** - Board: 38 / **P4.4-006**

## Documenting two decades of seismological station maintenance in Venezuela: lessons learned and future directions

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This study provides comprehensive documentation and detailed information on Funvisis' extensive experience in managing AS117 and AS118 for over two decades, as part of Venezuela's commitment to the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). This article presents a robust

methodology based on thorough records of both preventive and corrective maintenance carried out at these remote locations, as well as on evaluations conducted on-site and at the Funvisis analysis centre where the NDC operates. The recent joint maintenance effort at AS118 is the epitome of best practice. It involved experts from both the CTBTO and Venezuela and addressed issues related to expected degradation associated with the lifetime of measurement, communication, power and other parts and components. It also addressed related considerations for reassessing station locations, taking into account changing factors such as environmental noise, anthropogenic, security (including vandalism) and other varying energy requirements. Consolidating these experiences into a single paper provides invaluable information on how to effectively manage the stations. These results are of benefit to NDCs and all States Signatories in general, promoting a collaborative approach to seismological monitoring and improving the harsh conditions under which our secondary stations must continue to operate.

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**P4.4 International Monitoring System Sustainment into the future** - Board: 22 / **P4.4-082**

## The performance of back up power at KMBO primary seismic station post upgrade

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At the KMBO 3C primary seismic station, International Monitoring System and Global Communications Infrastructure (GCI) equipment are powered by 240 VAC mains power. A power stabilizer is installed, which regulates the input AC mains power voltage between 180V and 260V. Station visits for routine operation and maintenance are performed once every calendar month. Before 2021, the seismic station was characterized by rampant AC mains power outages and/or voltage fluctuations. The power outage problem was exacerbated by an aged backup power supply provided by 24 batteries. In addition, rampant GCI outages occasioned by a high threshold of GCI UPS battery capacity of 96% often caused data transmission outages to the International Data Centre. In order to mitigate the rampant mains power outages at KMBO, the station underwent a major power upgrade from August to October 2021 as per IRS-PR-KMBO-161955. The backup power system now consists of a Beloti Variatori SRI AC power stabilizer, 10KVA, 48V Vitron AC/DC invertor/battery charger and 24 pieces 2V, 3000AH RITA OPZV batteries IRS-CCN-KMBO-163645. The performance of the new power backup system is rated excellent. During SnT2025, we will demonstrate the excellent performance on the basis of recent mains power outages, which occurred from 16 to 17 April 2024 as per IRS-PR-KMBO-182162.

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# Technology and human resource in operation and maintenance

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The International Monitoring System network, the national networks of different countries, consists of various facilities and a variety of equipment and designs deployed in different parts of the globe. The operation and maintenance (O&M) of these facilities in order to achieve the required level of data availability and quality is very challenging and requires resource mobilization, planning, and management for optimization. The sustainment of these facilities requires modern technology, human resource availability, training, management, and sustainability. The advent of modern and new technologies has greatly impacted the dynamics of operations and maintenance, especially in view of the unpredictable climatic and global weather patterns. This presentation aims to discuss the predictive and analytic role of technology, such as machine learning and AI: their contribution to the development of measures and tools that lead to enhanced performance optimization, and also their limitations in the daily O&M activities. These tools help in the innovation and development in the state of health monitoring by station operators, timely notifications, equipment standardization, documentation, storage, and best practices in O&M. We further highlight the critical role of human intervention, the needs of human resources, the new challenges faced and some potential solutions.

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**Online e-Poster Session 2** - Board: 0 / **P4.4-162**

# Redundant communications in the tropic

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During the rainy season in Costa Rica there are problems with satellite communications. This is due to the large amount of rain and bad weather conditions. It is analysed as follows: the frequencies used in a VSAT with the International Data Centre (IDC) are between 4.172GHz to 4.174GHz and between 6.397 and 6.399GHz. Using the formula, we can find that the
wavelength of these frequencies are 71.9mm and 46.89mm.
Considering the above and that the annual average of rainfall exceeds 4000 mm in the area where the JTS station is located, there are periods in which the attenuation of the satellite signal is very high and could affect communication. Therefore, it is proposed to place a secondary communication system that does not transmit through the air like a business fiber optic service, whose main characteristic is that the
provider guarantees its stability to a minimum of 95% (considering breakdowns). The above, added to a parallel communication of the data to our National Data Centre and subsequently to the IDC, we would obtain backup in the communication and storage of data, as well as
continuity in a reliable manner.

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**P4.4 International Monitoring System Sustainment into the future** - Board: 40 / **P4.4-230**

## Improving Detection Capabilities: The Upgrading of CTBTO Auxiliary Stations in Indonesia

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) plays a pivotal role in global nuclear non-proliferation efforts through its extensive monitoring systems designed to detect natural phenomena and also nuclear explosions. The ongoing progress of upgrading CTBTO seismic sensors in Indonesia highlights the nation's commitment to supporting the International Monitoring System (IMS) in collaboration with the Indonesian Meteorology, Climatology, and Geophysics Agency (BMKG). Significant advancements have been made nationwide, particularly in improving six CTBTO auxiliary stations in Indonesia, which are integral to the global monitoring network. These enhancements focus on increasing detection capabilities and data reliability. Key initiatives include the integration of cutting-edge communication technologies, improvements in data collection systems, and the replacement of outdated sensors. These upgrades aim to enhance sensitivity, reduce latency, and ensure seamless data transfer to the IDC. The partnership between BMKG and the CTBTO is crucial for maintaining operational excellence, training local staff, and addressing the technological challenges posed by Indonesia's complex seismic environment. Initial findings indicate a marked improvement in data quality and detection performance, reinforcing Indonesia's role in the global seismic monitoring network. This development underscores the importance of ongoing technological advancement and international collaboration in fulfilling the CTBTO's mission to promote nuclear non-proliferation and enhance global security.

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**P4.4 International Monitoring System Sustainment into the future** - Board: 41 / **P4.4-644**

## Augmented State of Health Sensors for Predictive Failure analysis

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Continued sustainment of the International Monitoring System (IMS) network is of critical importance to the longer term viability of the Comprehensive Nuclear-Test-Ban Treaty. Increasing global costs and budget constraints may limit the level of future investment in the maintenance and operational costs of the IMS. To mitigate this financial restriction, individual sub-systems of radionuclide stations will have to demonstrate increased lifetimes between failures. This work presents initial efforts towards the augmentation of the existing state of health sensors deployed on radionuclide systems. Additionally, analysis techniques aimed towards the accurate prediction of subsystem degradation and failure is presented.

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## Lifecycle of IMS hydroacoustic hydrophone stations, and technical approach to their sustainment

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With the certification of the hydroacoustic hydrophone station HA4 Crozet in 2017, the International Monitoring System (IMS) hydroacoustic network became the first component of the IMS to be completely certified. Six of the 11 IMS hydroacoustic stations are cabled hydrophone stations with triplets of hydrophones suspended by risers in the deep sound channel; the remaining five are T-stations with nearshore seismometers placed on land. This work focuses on the analysis of the lifecycle of the hydrophone stations, considering separately (i) the onshore subsystem with the Central Recording Facility (CRF), on land and underwater nearshore trunk cables, and (ii) the further offshore underwater system (UWS) with trunk cables and hydrophone triplets in deep water. The lifecycles of each of these two subsystems differ by an order of magnitude; for example, the electronics components in the CRF have lifetimes around five years, while the “unrepeatered” undersea trunk cable can be expected to be functional for three to four decades if undamaged by external aggression. Approaches to sustaining these stations are described, and different scenarios are envisaged for UWS repairs in case of subcomponent failure, with the associated technical and economic efficiencies. The potential future role of modular design solutions is also discussed.

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**P4.4 International Monitoring System Sustainment into the future** - Board: 43 / **P4.4-691**

## Resilient Monitoring in Extreme Conditions: Sustaining the Warramunga Seismic Array

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PS02/WRA, the Warramunga Seismic Array in Australia's Northern Territory, operates in one of the most challenging environments within the International Monitoring System (IMS). Certified since December 2000, the station has been critical to the IMS global monitoring network. Recent engineering activities have focused on enhancing its resilience to environmental hazards, including flooding, bushfires, lightning strikes, and extreme temperatures. Key upgrades include improved grounding and lightning protection, enhanced intra-site communications, and power infrastructure improvements at both the central recording facility and remote elements. Planned projects involve upgrading flooding postholes for all 24 remote elements and fully modernizing both sensors and digitizers. These engineering activities highlight the IMS' commitment to station sustainment and resilience in harsh environments while adopting cost-effective and sustainable practices to ensure long term reliability and performance of the IMS network.

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# Modelling IMS seismic and infrasound networks sustainment needs: data-driven approach for IMS sustainment Planning

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The need for a clear and transparent approach for sustaining the International Monitoring System (IMS) network has grown since the early days of the Provisional Technical Secretariat (PTS), when activities primarily focused on the installation and certification of IMS facilities. Today, as much of the network is ageing, efforts have shifted towards modelling and anticipating future needs for the mid to long term, particularly in terms of financial resources. To address this challenge, a data-driven methodology was developed by the PTS for the seismic and infrasound technologies, using available data and expert insights to model IMS stations composed of subsystems and derive technical sustainment needs through risk analysis. Preliminary results from this approach have demonstrated its effectiveness, enabling better identification of future technical requirements through an informal paper presented at Working Group B. This approach, along with its assumptions, findings, and potential integration into PTS decision making, will be presented. Additionally, we have identified potential enhancements to the data-driven methodology, such as investments in enhanced state of health monitoring, quality assurance, and failure analysis, which could further refine the approach and improve its accuracy in informing decision makers and engineers about future needs for the IMS facilities.

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**Online e-Poster Session 2** - Board: 0 / **P4.4-728**

## Predictive Analytics for radionuclide systems of the International Monitoring System

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Sensor data from radionuclide systems within the International Monitoring System (IMS) provides critical information about the operating status of a given station. Typically, station operators monitor sensors for significant deviations from normal operation to signify a potential problem and take some action. Detecting subtle changes over long periods of time always presents a challenge, but such a detection could provide valuable insight into an impending failure. To address this, Pacific Northwest National Laboratory is currently working towards the idea of predictive analytics through a comprehensive strategy. The idea is to use several techniques to identify critical failures early, such that they can be mitigated before becoming catastrophic. This presentation will highlight recent advancements and discuss the overall strategy.

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**P4.4 International Monitoring System Sustainment into the future** - Board: 45 / **P4.4-744**

## Failure Analysis as support to enhance the sustainment of the International Monitoring System (IMS) network: existing challenges and perspectives.

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The establishment of the Comprehensive Nuclear-Test-Ban (CTBT) International Monitoring System (IMS) network has progressed at an impressive pace in the last 25 years: to date, 90% of the network has been built and is operational. While major efforts are made by the Provisional Technical Secretariat (PTS) to complete the establishment of the network, the challenge of sustaining the IMS facilities, maintaining their high level performance, constitutes a major focus for the PTS. Equipment, infrastructure, power, communication and lightning protection systems are among several station components experiencing ageing and obsolescence and need to be timely replaced to minimize the risk of data loss. Keeping abreast of new technological and engineering solutions to support and rejuvenate the IMS network, thus restarting the lifecycle of IMS facilities, is a crucial component of the PTS activities. Analysing the past station failures and identifying the causes of data loss is another key activity in support of IMS sustainment: the PTS has been engaged for several years in this study, using the Failure Mode, Effects and Criticality Analysis approach. This work presents an overview of the results achieved to date using failure analysis and discusses the existing challenges associated to the current methodology, proposing potential future perspectives.

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**P4.4 International Monitoring System Sustainment into the future** - Board: 46 / **P4.4-802**

## Collaborating with Station Operators for Developing the International Monitoring System Sustainment Strategy

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Collaborating with station operators and representatives from National Data Centres has been an important part in developing a sustainment strategy for the International Monitoring System (IMS), operated by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). A questionnaire was distributed to all station operators and representatives from National Data Centres. The questionnaire included 40 questions grouped in seven categories: 1) station information and characteristics; 2) lifecycle; 3) infrastructure; 4) environment; 5) climate change; 6) vandalism; and 7) station operator. It aimed to obtain information that could contribute towards the development of the IMS sustainment strategy, especially in areas where little is known. The results show that most of the systems have been in operation for more than 16 years; the main reasons for major changes in the systems are deterioration owing to changes in the station environment and end of life replacement. About 60% of stations might require some level of work on their infrastructure, mainly related to the power system or housing. The participants identified that the main risk the stations face is related to the environment, and an increased frequency of extreme weather events, highlighting a further upgrade to the station infrastructure to mitigate against climate change.

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**P4.4 International Monitoring System Sustainment into the future** - Board: 47 / **P4.4-804**

## Building the International Monitoring System Sustainment Strategy through international expert consultation and collaboration

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Although more than 90% of the International Monitoring System (IMS), operated by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) has been installed, over the next decade, a large proportion of IMS stations will reach the milestone of 20+ years post-certification with continuous operation. Thus, in order to develop a strategy for the long term sustainment of the IMS, the expected life spans of stations and their subsystems should be understood and a good technical methodology to determine the needs of the IMS should be developed. This fact caused the CTBTO to examine various sources of information and expertise that could be utilized to build upon its in-house expertise and to obtain a solid basis for the strategy. One such source of information was a group of international experts that formed the Guidance Committee for IMS sustainment. These experts have experience in operating and maintaining large (sometimes global) monitoring networks from

different technologies and also deal with the complexities of developing strategies for the future sustainment of the equipment installed at stations. The experts have proved to be crucial as "sounding boards" for guiding our understanding of the best methods to utilize within the sustainment strategy.

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**P4.5 On-Site Inspection Team Functionality** - Board: 29 / **P4.5-043**

# Lead Free Radiation Protection Clothing Solution for Inspection Team

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In the practical scenarios, On-Site Inspection (OSI) could be conducted in any place that is in an environment with radiation hazards. Traditional radiation shielding materials are mainly made of lead-containing rubber materials. Although lead is a good radiation shielding material, its high toxicity, overweight and unstable shielding efficiency also cause irreversible damage to the human body and the environment during the use and disposal process. Lead-free flexible radiation shielding composites using tungsten, bismuth, rare earths and other materials can effectively compensate for the shortcomings of lead-containing materials. For the integrated CBRN protection needs of PPE in OSI scenarios, the shielding materials can effectively solve the critical problems, such as shielding efficiency, comfort, heat dissipation, and environmental protection. This work carried out a practical clothing solution for the OSI inspection team based on different roles and functionalities of the inspectors, with theoretical analysis and test results being given for realistic challenging OSI scenarios.

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# Anti-Counterfeiting Total Solution to OSI

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On-site inspection (OSI) is a verification mechanism that would strengthen the confidence among States in the Comprehensive Nuclear-Test-Ban Treaty, especially the confidence between IT and ISP during the real OSI. To achieve this goal, a culture of anti-counterfeiting for OSI would be essential for building confidence in OSI activities. Quantum Stealth Code is based on a kind of special ink made of nano-level particles extracted from rare earth. After being printed on the surface of items, the Quantum Stealth Code is invisible to the naked eye but could be visible only under a certain light with certain spectrum frequencies. The encrypted code can be printed on the surface of any items of OSI, including sample containers in the shape of characters, 2-D bar-code and dot matrices. This work put forward an anti-counterfeiting total system solution composed of a Quantum Stealth Code system, a specially designed printer, and a customized handheld PDA reader, which would provide authentication of the origin and chain-of-custody management of any OSI equipment and samples, or other items that need proof of their authenticity. This system has been applied to the marking of small arms and light weapons, and ammunitions, and could also be widely applied to the whole CTBTO.

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# WebGL and B/S Based GIS Platform for OSI Search Logic Development and Operation Support

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After the triggering event and political decision to dispatch the inspection team to the inspection area, on-site inspection (OSI) would be initiated at a geological location. Before the inspection team arrives at the point of entry, OSI can only be primarily planned on a GIS platform with the support of International Data Centre data input. The inspection area with the boundaries would be clarified, the base of operations location would be decided, initial overflight and the first period of inspection activities plans would be made. The inspection area could be familiarized by the inspection team, possibly managed access areas could also be set up, mainly by means of this GIS platform. This work would propose a WebGL & B/S Based GIS system to provide the previously mentioned support to

OSI. The system is based on open source software and data, which can be installed on a zero-client server without connection to any other information sources, including the internet. It could achieve 3-D visualization of the inspection area with high fidelity. In the meanwhile, it could also provide spatial analysis to support the OSI mission. It has the capacity for OSI data management with the professional guidance of the Provisional Technical Secretariat experts. The system is highly open and adaptable to other third-party software systems.

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## Real time three dimension radiation imaging Compton camera for radiation safety of base of operations

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Base of operations (BOO), as the accommodation and working base of an inspection team, would be a very important facility for an OSI mission. As the OSI would be based on the heavy culture of nuclear, the radiation safety of BOO has its special significance. In the practical case, continued monitoring of the radiation level and the identification of the radioactive sources at BOO, would have significant operation value. This work would propose a real time three-dimensional radiation imaging Compton camera. The camera could work at room temperature. It has high detection efficiency and high energy resolution. It could not only provide real time energy spectrum of radioactive isotope and identification, most importantly, it could also provide the real time distribution of radioactive materials in the environment. Deployed at several locations of the BOO, they could protect inspectors from radioactive contamination at their office and home. Deployed in the decontamination area, it would ensure the decontamination effect. The real time three-dimension radiation imaging Compton camera would safeguard the nuclear radiation free BOO.

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## On Site Inspection: New approach to contamination control in the Field and at Base of operation.

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During on-site inspection (OSI) training or small exercises focused on specific techniques, decontamination control procedures were typically the subject of discussion between IT leadership due to the fictitious scenario, human resources, equipment deployed and limited time. The goal of this presentation is to show and discuss a new approach to establishing a decontamination line, standardizing the decontamination line configuration that we could use depending on the complexity of the scenario, and it focuses on filling the gap between training, exercises and real scenarios. Three levels of decontamination configurations will be presented: no contamination, potential contamination, and confirmed contamination according to information available from the field. As a result, we could have more flexibility during OSI training, have consistency in what we teach or learn without losing the health and safety culture and the true purpose of decontamination, and keep inspectors safe.

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## The BUE24 Radionuclide Scenario and Updates Needed Before IFE

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The Build-Up Exercise 2024 (BUE24) in Hungary was the first large scale on-site inspection (OSI) exercise to involve a working tunnel complex, opening up new possibilities for the Scenario Task Force designing the exercise scenario. A scenario was developed that involved both radioparticulate detections at the tunnel entrance and radioxenon detections from shallow sub-surface samples taken in the vicinity of the hypothetical underground nuclear explosion site in the tunnel complex. The BUE24 radionuclide control team needed to make quick adjustments when their process of radioxenon injections into the analysis equipment encountered problems. Details of the scenario will be shared, and also adjustments that are planned for the control team's radioxenon injection process at the upcoming Integrated Field Exercise.

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# Challenges of Over-Reliance on Software and Applications during CTBTO On-Site Inspections

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On-site inspections (OSI) serve as the ultimate verification measure under the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The Geospatial Information Management for OSI (GIMO) system is critical in these inspections, facilitating mission planning and decision making through advanced geospatial and analytical tools. While GIMO represents a technological leap in inspection methodology, its dependence on software and hardware introduces unique challenges, especially in field deployment in unknown and unpredictable environments. These challenges can be broadly categorized into natural barriers and technological barriers. Natural barriers, such as rugged terrains and extreme weather conditions, can compromise GPS accuracy, digital map reliability, and device functionality. High humidity, heat, or cold can affect tablet performance, while unstable internet connections hinder real time updates. Technological barriers, including software bugs and cybersecurity vulnerabilities, further challenge seamless operation. Inspectors' proficiency with GIMO is another critical factor, as inadequate training can lead to errors and inefficiencies. To address these challenges, strategies such as enhancing inspector training, incorporating hybrid methods that balance digital tools with traditional techniques, and improving system resilience are essential to ensuring uninterrupted field missions, the most important element of an OSI. By mitigating these vulnerabilities, GIMO can be effectively optimized for OSI operations, ensuring its reliability in critical missions.

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# NaIL-detector characteristics as neutron detector and gamma detector

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For verification purposes, it is crucial to obtain comprehensive information time-efficiently. Alongside gamma measurement results, neutron data plays a key role in the evaluation. A promising approach is the simultaneous detection of gamma and neutron radiation using a combined detector, such as the NaIL detector. It is based on sodium iodide (NaI). The NaI is doped with <sup>6</sup>Li, enabling neutron detection through the <sup>6</sup>Li(n,t)$\alpha$ reaction. The secondary particles produce detectable scintillation light pulses. Due to the reaction's high Q-value of 4.78 MeV, these signals are comparable to those of high energy gamma photons. The discrimination of neutron and gamma radiation is realized by pulse shape analysis. Previous work focused on neutron detection using various neutron sources with and without HDPE moderation. In addition to these investigations, this study examines the performance of the NaIL detector in gamma detection. The aim is to evaluate the specific gamma quality and performance of the NaIL detector compared to common NaI. Different gamma sources are used to assess parameters such as the FWHM resolution, providing

insights into their suitability for high precision gamma spectroscopy, simultaneous with neutron detection. This type of detector may significantly enhance the capability of gamma and neutron detection during on-site inspections.

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## Electronic & Magnetic Sensing Based Integrated Simulation Platform System Solution to OSI Trainings and Exercises

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On-site inspection (OSI) of nuclear test events is different from other arms control verification activities, due to the risks of possible nuclear radiation hazards. Consequently, OSI training and exercises can be practical and meaningful only if they can be conducted under a nuclear radiation environment. However, this would raise great health and safety challenges for inspection team members. This work would carry out an electronic and magnetic sensing based integrated simulation platform system solution to nuclear test event OSI training and exercises. Electronic and magnetic devices could be applied to replace the radioactive sources during the training and exercises. After being detected by the corresponding specially designed detection equipment, the data would be sent from the equipment to the integrated information management platform for data visualization, situation awareness of radioactive hazards and signatures, training, or exercises activities support. Simulated radioactive sources and detection equipment could be used multiple times for SOP practice without any threat to the inspection team's health and safety.

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## A realistic Inspected State Party as a required OSI integrated exercise participant for the application of the Inspection Team Functionality

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The inspected State Party (ISP) is a key role for on-site inspection (OSI) integrated exercises as it represents the sovereign rights of the inspected State, and thus keeps the integrated exercise play realistic, while providing a view of what may be experienced by an inspected State and what they may be required to provide in the case of hosting an actual on-site inspection. We will discuss the ISP role in the Build-Up Exercise 2024 (BUE24), starting from how the ISP was trained, equipped and resourced, and we will explore how this iteration of the ISP differed from previous integrated exercises conducted a decade earlier. In particular, we will focus on the impact on the inspection team functionality of the ISP strategy of providing differing plausible explanations of the triggering event for the BUE24 scenario, using the ISP national implementation requirements concerning private property, and how that worked during the exercise.

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## Radiation protection in On-Site Inspections (OSI)

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A nuclear weapon explosion emitted radioactive contamination into the environment. The Comprehensive Nuclear-Test-Ban Treaty (CTBTO) in paragraph 69 of the protocol on “Inspection Activities and Techniques” refers to the tests that must be collected as evidence to prove the origin of the explosion. These samples are collected in a radiologically contaminated area with a risk to inspectors’ health. To work in radiologically contaminated areas requires radiological protection measures to reduce the inspectors’ dose received due to ionizing radiation. The potential risks for inspectors are external irradiation and external and internal contamination. External irradiation due to radioactive sources that are outside, to reduce it, tools such as distance, time and shielding are used. The measurement of the dose received is performed through dosimeters. Internal contamination is due to the incorporation of radioactive substances into the body through inhalation, ingestion, or wounds. The most appropriate method to avoid contamination is to use Personal Protective Equipment (PPE). Individual monitoring of internal contamination is controlled by in vivo measurements with body radioactivity counters and in vitro urine analysis. To have knowledge and training in the use of these tools and following procedures step by step helps to reduce risks in on-site inspection activities.

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# Bridging the gap between On-Site Inspection and Integrated Field Exercise

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An Integrated Field Exercise (IFE) is the most advanced training procedure that simulates an on-site inspection (OSI) and is designed to train inspectors, providing hands-on experience of a potential OSI. Once the Treaty enters into force (EIF), conduct of an OSI on a request of an ambiguous event may become a reality and the OSI inspectorate shall have adequate training to deliver the expected outcome. Hence, the IFE in theory shall provide an environment that resembles an OSI. However, the artificiality of an IFE, compared to OSI, is inevitable and cannot be avoided. IFE is privileged for an extended luxury in selecting locations, prior arrangements that could have been done under strict timelines during an OSI, and tolerance on the number of agreed inspectors and inspector assistants as per the CTBT Protocol. Towards directing a pre-determined scenario of an IFE, injects play a prominent and decisive role, which is a necessity, yet partly modify the focus of the inspection team. Though added artificialities and pre-designed injects are important elements to conduct a successful IFE, the degree of deviations has to be mapped out carefully with the right balance that shall not leave an unbridgeable gap between the IFE and the OSI.

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# Enhancing On-Site Inspection Capabilities Under the CTBT: Integrating Lessons from the Co-Expertise Process in Radiological Risk Communication and Stakeholder Engagement

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On-site inspections (OSIs) under the Comprehensive Nuclear-Test-Ban Treaty (CTBT) require inspectors to operate in complex environments where radiological concerns may arise. While their primary objective is technical verification, inspectors may need to address stakeholder uncertainties regarding radiation risks. Drawing on lessons learned from the aftermath of the Chernobyl and Fukushima accidents, this study examines how elements of the co-expertise process, such as structured dialogue, participatory radiation monitoring, and trust-building strategies, can be adapted for OSI training and field operations. By incorporating methodologies that foster stakeholder engagement and transparent risk communication, inspectors can improve situational awareness, facilitate cooperation with host State personnel, and enhance public confidence in OSI findings. This study also examines how digital tools and AI-assisted decision making can support interactive risk assessment during inspections. The findings highlight the potential for integrating stakeholder-inclusive radiological risk management approaches into OSI protocols, contributing to more effective and resilient inspection missions in diverse operational settings.

Keywords: On-Site Inspection (OSI), CTBT, Co-Expertise Process, Radiological Risk Communication, Stakeholder Engagement, Trust-Building, AI in Nuclear Verification

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# Development of an OSI Software Package for Gravitational Field Mapping Data Processing

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Gravitational field mapping (GRV) is one of the techniques that an inspection team can use during a Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) on-site inspection (OSI). High precision microgravity surveys may be able to detect the gravitational anomalies created by subsurface observables related to an underground nuclear explosion, namely the presence of a cavity around the detonation point and surrounding zones where petrophysical changes have occurred, a collapse chimney or an apical void. The amplitude of the gravitational anomalies created by such observables may be very small, depending on the density contrast, the size, and depth of the observables. Therefore, it is necessary to process the GRV data accurately, especially to remove the effect of a whole range of corrections that may create anomalies larger than the signal of interest. We present a tailored Python software package (source code based on open source libraries available at CTBTO) that we developed for the processing and visualization of GRV data. The software, accessible through a user friendly graphical interface, imports raw data obtained from the gravimeters currently operated by the CTBTO OSI Division and allows the application of a complete set of corrections (instrumental, time variable, location based and terrain corrections, plus outlier removal) to obtain and display gravity values.

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# OSI Communications System

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The On-Site Inspection (OSI) Communications System is an advanced framework enabling seamless and secure communication during inspections under the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Designed for rapid deployment, potentially anywhere in the world within six days, it supports real time coordination among inspection team members and between field teams and the Operations Support Centre (OSC) at headquarters. The system is capable of supporting operations across an inspection area of up to 1000 km², even in remote locations with minimal infrastructure. The system leverages state of the art technologies such as broadband satellite platforms, including Starlink and OneWeb, complemented by UHF and VHF radio networks and Iridium satellite phones. These tools ensure robust global coverage, secure data transfer, and reliable voice communication independent of local infrastructure. By incorporating redundancy and overlapping communication methods, the system maintains operational continuity under challenging conditions. With rapid deployment capabilities, the system adheres to the Treaty's stringent lead time requirements, becoming fully operational within days. Designed to withstand diverse terrains and challenging environments, the OSI Communications System integrates innovative technology and lessons from field exercises, setting a global benchmark in supporting non-proliferation and verification efforts.

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# OSI Build-Up Exercise 2024

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On-Site Inspection (OSI) Build-Up Exercise 2024 (BUE24) was a medium scale exercise focusing on the continuation period of an OSI, conducted in Hungary and involving over 150 participants from 37 States Signatories over three weeks in June-July 2024. Considerable work has been undertaken by the OSI Division and wider Provisional Technical Secretariat to develop OSI capabilities since the last large scale Integrated Field Exercise (IFE) in 2014, held in Jordan. Concepts, policies, and procedures have been updated, together with considerable investments in new software systems, equipment, hardware, and physical infrastructure. Consequently, BUE24 was designed to allow for the integrated testing of OSI's various techniques, equipment and procedures in a topographically varied inspection area, as well as to serve as a partial rehearsal for selected surrogate inspectors in advance of an IFE. This poster shall provide information on the exercise aim, objectives, scope and availability of techniques, scenario development and implementation process, role of the Operations Support Centre and independent evaluation. Furthermore, it shall summarize specific key findings and recommendations that are being addressed in advance of future OSI exercises.

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# OSI Integrated Field Exercise

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The On-Site Inspection (OSI) Exercise Programme for 2022-2025 is envisaged to culminate with the conduct of an Integrated Field Exercise (IFE): the largest and most complex multinational exercises in the field of chemical, biological, radiological, and nuclear non-proliferation and arms control. The primary aim is to test and demonstrate the capability of the Comprehensive Nuclear-Test-Ban Treaty on-site inspection element of the verification regime to clarify whether a nuclear test or explosion has been carried out in violation of the Treaty. An IFE provides an unrivalled platform to test various operational, procedural and technical elements of an OSI in an integrated manner. This IFE shall be designed to demonstrate both maintenance of specific existing OSI capabilities and also newly developed or updated elements, and will allow for the review of policy, operational, operations support, logistical and technical capabilities from a holistic, cross-cutting perspective. The next IFE is expected to involve up to 200 participants, over a period of six to seven weeks, and an inspection area approaching the Treaty-permitted 1000km2. This poster shall provide information on the exercise design, schedule, scope, location, expected challenges, as well as the general status of the planning and preparation process.

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# Operationalization of the OSI Operations Support Centre

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In preparation for the next on-site inspection (OSI) integrated field exercise (IFE), the OSI Operations Support Centre (OSC) at the Provisional Technical Secretariat underwent several process changes aimed at improving the OSC capability to support the inspection team and to support the PTS' senior management in its OSI-related activities. The changes include increased efficiency, new communication tools with the inspection team and within the OSC, new tools to streamline responses to inspection team requests for support and for OSC reporting, and improved processes for maintaining up to date knowledge about the progress of inspection. All those new developments were tested during the Build-Up Exercise 2024 (BUE2024), which simulated the continuation period of an OSI. This poster illustrates the new developments of the OSC capabilities, the key roles of the OSC and how it functioned during BUE2024, and the way ahead to ensure its preparedness for future OSI exercises.

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## OSI Directed Exercises 2023

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The On-Site Inspection (OSI) Directed Exercises in 2023 were the first field exercises conducted under the framework of the OSI exercise programme for 2022-2025 and the first field exercises conducted since the Integrated Field Exercise in 2014 (IFE14). The Directed Exercises aimed to demonstrate and evaluate progress made in the development of selected OSI technical and operational capabilities since 2015, ensure that the existing OSI capability have been maintained; identify areas for further improvement of OSI capabilities and processes in preparation for entry into force; and promote and raise awareness about the Treaty, its verification regime and in particular the OSI element. Consequently, three Directed Exercises were conducted simultaneously in September 2023 in Bruckneudorf, Austria. They comprised the Directed Exercises on Field Operations Support, the Directed Exercises on Environmental Sampling and OSI Field Laboratory, and the Directed Exercises on Data Flow Management. This poster shall provide information on the DEs23 aim and objectives, concept, participants, and technologies. Furthermore, it shall summarize specific key findings and recommendations that are being addressed in advance of future OSI exercises.

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## Enhancing On-Site Inspection Training through Online and Computer-Based Training

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On-Site Inspections (OSIs) are critical to the Comprehensive Nuclear-Test-Ban Treaty Organization's (CTBTO) mission of verifying compliance with the Treaty. The complexity of an OSI necessitates continuous and effective training for surrogate inspectors of the non-standing inspectorate. The computer-based and online training programme is designed to prepare surrogate inspectors for in-person courses, maintain high readiness levels, and ensure an active roster status. The OSI learning management system (LMS) hosts scenario-based e-learning, video tutorials, virtual reality tours, modular learning paths, and synchronous activities such as webinars and remote facilitator-led software training and demonstrations. Additionally, self-paced remote software training is delivered via personal cloud-hosted virtual machines, enabling inspectors to remotely refine their skills on key OSI software. Features like real-time feedback, interactive multimedia, and assessments contribute to an engaging and effective learning experience. This approach accelerates onboarding, provides on-demand access to training resources, and ensures surrogate inspectors stay updated on new topics while reinforcing core OSI concepts through online refresher training. It complements in-person training by supporting preparatory and post-course refresher activities. This poster provides an

overview of the online training programme, challenges, and potential for integrating artificial intelligence and advanced virtual and augmented reality technologies into OSI online training offerings.

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## Requirements and management of support infrastructure for large scale OSI exercises

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Large scale on-site inspection (OSI) exercises – especially with limited resources directly available on site – require robust support infrastructure well beyond the standard support requirements of an inspection team. Additional exercise participants and teams (such as personnel playing notional "inspected State Party" roles, exercise control team, external evaluation team, management team, as well as host country support personnel, contractors, visitors) require a wide range of support and infrastructure integrated into a coherent support system to function properly. At the same time, these "Non-IT" support elements must be independent and separated from the "in-game" inspection team support capabilities to allow free play for the exercise players and the testing and validation of IT support procedures, training and equipment as part of the exercise. The build-up exercise in 2024 (BUE24) was the first OSI exercise where a full-scale support infrastructure, including "Non-It" teams was set up as opposed to ad-hoc use of components in previous exercises. This poster aims to visualize the methods this support infrastructure was deployed, maintained and re-deployed during BUE24, along with key challenges and some overlaps identified. These lessons identified are used to further improve the exercise support concept and the exercise support infrastructure, with results to be fully implemented during IFE.

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**P4.5 On-Site Inspection Team Functionality** - Board: 31 / **P4.5-586**

## OSI Health, Safety and Security

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A robust health, safety, and security management system is foundational to ensuring that on-site inspection (OSI) activities under the Comprehensive Nuclear-Test-Ban Treaty are conducted safely, efficiently, and effectively while maintaining the trust and cooperation of all parties involved. A build-up exercise and prior training highlighted three vectors which are integral to instilling a health, safety and security culture that is applicable and flexible enough for the specific challenges of an OSI. Procedural documentation provides the basis for health, safety, and security during OSI activities. It establishes standardized guidelines and protocols that are applicable to enable inspections in diverse and challenging environments. Training is essential for preparing inspection teams to apply health, safety, and security protocols effectively in real world scenarios. It equips inspectors with the knowledge and skills needed to manage various risks and to ensure a successful deployment. Equipment that is appropriate, effective, and current is essential to ensure both the safety of inspectors and the security of the inspection process. Proper equipment helps minimize health risks, prevent accidents, and enable the inspection. This poster explains the implementation of this health, safety, and security framework along these three vectors. This is applicable to all aspects of an OSI, from current training and exercises, through to post entry into force.

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# New Technology Infrastructure at the On-Site Inspection Field Laboratory

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In preparation for the Integrated Field Exercise (IFE) and based on lessons learned from the past field exercises, the Equipment and Implementation section of the On-site Inspection (OSI) Division of the Provisional Technical Secretariat has redesigned the technology infrastructure of the OSI field laboratory for full compatibility of computing platforms, internal data transmission and data analysis tools with the GIMO management system currently in use during an OSI. A GIMO laboratory application ("LabDash") has been developed and tailored to automate the transfer of sample metadata and raw data from the GIMO field application to the OSI field laboratory. LabDash ensures that the sample and sample data chain of custody, manages spectrum acquisition, data analysis and allows Reviewed Radionuclide Reports classification and delivery. Automatic analysis and interactive data review are performed with OSI-tailored Comprehensive Nuclear-Test-Ban Treaty Organization data analysis tools (ONiaB_P and ONiaB_NG), interconnected with LabDash. Hardware and software redundancy, hot spare configurations, as well as tailored backup strategies for data, software and hardware are implemented at the OSI field laboratory. The new OSI field laboratory IT infrastructure is ready for implementation at the upcoming IFE.

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# OSI Radionuclide Techniques readiness to support the On-Site Inspection Team Functionality

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In preparation for the Integrated Field Exercise (IFE) and in line with the capabilities developed with past field exercises and expert meetings, the On-site Inspection (OSI) Division of the Provisional Technical Secretariat has entered into a new stage of development. Among radionuclides techniques in use at OSI, systems which are operational for gamma radiation monitoring and low resolution energy resolution analysis (GRM/ERAL), for in situ high resolution energy resolution analysis (ERAH) and for environmental sampling (ENV) had been subject to periodic review of systems performance and obsolescence management; regular maintenance, ad-hoc troubleshooting, and tailored upgrades enhanced systems sustainability and standardized operability in the field. Lessons learned during the Directed Exercise in 2023 and the Build-Up Exercise in 2024 (BUE24), as well as recommendations from inspectors participating in the BUE24 and the IFE in 2025 preparatory training in 2024, were implemented: systems robustness was enhanced, procedures were updated and Field Guides developed. Field exercises and training sessions held during 2024 confirmed the operational status and readiness of radionucide techniques for OSI deployment at the upcoming IFE, in support of the OSI Inspection Team Functionality.

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# Necessity of a prototype test-site for optimization of OSI training

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Once the Treaty enters into force (EIF), the on-site inspection (OSI) team could be in a position to conduct an OSI almost in any environment. The main training process of the OSI Inspectorate, Integrated Field Exercise (IFE), could not practically be performed in demanding and different environments with all possible scenarios. Hence, building up plausible alternatives could be an added asset in making a versatile OSI inspectorate. Since the Training Manual of the OSI was prepared according to the OSI-specified techniques, the technology has progressed immensely. Presently, advanced training on many complex objectives is partially conducted via computer-aided simulations and prototype settings that are cost-effective and provide room for a wide range of scenarios to be tested. Potential OSI has many diverse technical elements, besides the logistical challenges, and these elements could be tested in an integrated manner with the aid of a prototype test site. This

proposed test site could enable the generation of different environments and scenarios based on simulations with the assistance of modern technology. Such an initiative could serve as an auxiliary to an IFE, where all the elements are tested with timelines resembling a potential OSI.

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## Innovations to consider in overflight training for On-Site Inspections

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The effective implementation of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) requires meticulous planning and execution of on-site inspections (OSI), essential for verifying compliance with the CTBT. A crucial component of an OSI is inspection via overflight, which provides comprehensive data much needed to narrow down the search area and support ground operations. Innovative training methodologies designed to enhance the overall readiness of inspectors and thus the outcome of overflight missions are reviewed. Integration of advanced simulation technologies, including virtual reality and artificial intelligence, to create immersive training environments for inspectors is suggested. These technologies offer realistic scenarios enabling inspectors to develop critical decision making skills in a controlled setting, which complement existing training methodologies. Additionally, the use of unmanned aerial platforms in training will be analysed for their potential to offer safe, cost-effective, and versatile practice opportunities. Through these cutting-edge approaches, the CTBTO can ensure that its inspection teams are equipped with the skills and knowledge needed to conduct successful overflight operations, ultimately strengthening the integrity of the CTBT verification regime.

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## Improving the Effectiveness of On-Site Inspections in the Monitoring of the Comprehensive Nuclear-Test-Ban Treaty

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A method for assessing the reduction in effectiveness of on-site inspections, taking into account the frequency and duration of potential illnesses among inspection team members, as well as recommendations for reducing the likelihood of these illnesses, has been developed. The models used account for the geographical and climatic characteristics of the regions, as well as the season during which the on-site inspections are conducted.

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## Open cast mine explosion confirmation in South Africa with infrasound waves recorded at station I47

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Seismic events in South Africa are recorded by the national seismograph network and located with the SeisComp software. Seismic events include earthquakes, mining-related events associated with deep gold and platinum mining, and explosions that occur in opencast mines. Suspected explosions are identified through their geographical association with opencast mines and the time-of-day. From April 2024 onward, open cast mine blasts whose infrasound waves are recorded at station I47, South Africa, are analysed and if they meet the acceptance criteria confirmed as explosions. The confirmation criteria for the analysed waves are: (1) the back azimuth from station to explosion epicentre is within 8 degrees, (2) predicted travel time is within 7 minutes assuming a constant velocity of 330 m/s and (3) waves have an apparent velocity between 220 m/s to 440 m/s. Infrasound signal analysis is undertaken with the Infrapy infrasound analysis software. A total of 27 of 176, 31 of 191, 26 of 132, 57 of 351 and 61 of 507 suspected explosions were confirmed for April, May, June, July and August, respectively, with more events expected to be confirmed as the routine seismic analysis continues. Once confirmed the event type is updated from ‘suspected’ to ‘confirmed’ explosion.

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## Forecasting tsunami hazards for Eastern coastal regions of India and Sri Lanka: a predictive approach to risk mitigation

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The method of tsunami splitting is applied to analyse tsunami hazards along the eastern Indian coastal regions, specifically the states of West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, the Andaman and Nicobar Islands, as well as Sri Lanka. This approach involves segmenting the tsunami event into distinct phases—deformation, propagation, and inundation—and simulating each phase using Finite Difference Models. For this, coastal areas divide into high-resolution grids for detailed analysis, providing forecasts of maximum wave heights and inundation extents for both realistic and worst-case scenarios. The analysis includes 45 high-resolution grids (with resolutions finer than 1 arcsecond) for the Eastern Indian Coast, 13 grids for the Andaman and Nicobar Islands, and 17 grids for Sri Lanka. The forecast anticipates potential maximum wave heights and inundation levels, revealing that Tamil Nadu could experience waves reaching up to 5.5 m with velocities of up to 20 km/h. The Andaman & Nicobar Islands may see wave heights as high as 15.5 m, with speeds up to 45 km/h, while Sri Lanka might encounter waves up to 11.4 m at speeds of 130 km/h. This assessment provides essential data to enhance preparedness, guide mitigation strategies and strengthen coastal resilience in vulnerable areas.

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## Seismic hazards in Jordan: integrating regional fault systems for enhanced earthquake early warning

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Jordan's seismicity is heavily influenced by the Dead Sea Transform Fault (DST), a significant tectonic boundary between the Arabian and African plates, posing the highest seismic risk to the region. Historical earthquakes, including those in 749 AD and 1033 AD, highlight this threat. Other regional sources, such as the Zagros Fold and Thrust Belt in Iran, the Red Sea Rift and the Cyprus Arc, also contribute to Jordan's seismic activity.

The 6 February 2023, Turkey earthquake (magnitude 7.8) further underscored the region's vulnerability, with strong tremors felt in northern Jordan. The 1995 Gulf of Aqaba earthquake (magnitude 7.2) exemplifies additional risks. To mitigate these hazards, this proposal advocates for the development of an Earthquake Early Warning System (EEWS) in Jordan, utilizing local and regional seismic data, including that from the International Monitoring System (IMS) of the CTBTO, to enhance detection capabilities and emergency response.

Political challenges, including the need for regional cooperation and data sharing, as well as securing funding and support in a resource-constrained environment, must be addressed to successfully implement the EEWS, thereby improving earthquake preparedness and community safety in Jordan.

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## Tsunami modelling generated by submarine landslide (non-seismic) in the Pelabuhan Ratu area, West Java, Indonesia

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The history of earthquakes in the southern region of Java Island has seen large earthquakes with Mw above 7.0, including earthquake and tsunami events in 1921 (Mw 7.6), 1994 (Mw 7.6), 2006 (Mw 7.7) and 2009 (Mw 7.3) which occurred along the Java subduction. The location of the tsunami modeling study with coordinates 6,750 LS - 7,499 LS and 106,249 BT - 106,750 BT. The study was conducted through a tsunami scenario modelling simulation generated by the potential of earthquakes in the bay area, the landslides and the combination scenario. The M6.7 and M7.3 earthquake scenarios in the direction of the Cimandiri fault with a thrust fault mechanism will drag three landslide blocks along the bay and cause a tsunami. Based on estimates, the highest tsunami is 3.8 meters in Cisolok District and the calculation of tsunami inundation to the farthest land on Pelabuhan Ratu Beach is 516 meters. Based on the worst case scenario, the tsunami level in Pelabuhan Ratu District was recorded at 2.8 m and 3.8 m in Cisolok District. The height of the tsunami based on the model scenario is classified as dangerous and very dangerous with the estimated tsunami waves arrival time around 1 minute.

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**Online e-Poster Session 2** - Board: 0 / **P5.1-027**

## Artificial intelligence and the CTBTO: a SWOT analysis in the context of 12 global megatrends

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This paper presents a detailed analysis of 12 global megatrends — including technological advancements, climate change and sustainability, energy transition, demographic shifts, migration flows, the circular economy, smart cities and urbanization, economic restructuring, cybersecurity threats, health and wellness advancements, changes in consumer behavior, and geopolitical and strategic shifts — and examines their implications for the CTBTO's mission and activities. By integrating Artificial Intelligence (AI) into its operations, particularly in the International Monitoring System (IMS), data analysis, on-site inspections and capacity building, the CTBTO can significantly enhance its verification capabilities, improve threat detection, strengthen cybersecurity and engage more effectively with diverse demographics. A SWOT analysis highlights strengths such as advanced AI algorithms and enhanced monitoring systems, weaknesses like dependence on technology and workforce adaptation challenges, opportunities including partnerships for sustainable innovation and supporting

global energy transitions, and threats such as escalating cyber risks and geopolitical complexities. Leveraging AI allows the CTBTO to capitalize on strengths and opportunities while addressing weaknesses and mitigating threats. Balancing innovation with risk mitigation strategies and fostering global collaboration are essential to maximize AI's benefits, thereby reinforcing the CTBTO's mission to ensure a nuclear-test-free world while adapting to an evolving global landscape.

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**P5.1 Synergies with Global Challenges** - Board: 15 / **P5.1-036**

## The Climate Cost of Maintaining Nuclear Deterrence: Increasing Awareness on the Synergy Between Nuclear Weapons and Climate Change

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Proponents of nuclear deterrence generally see it as a stabilizing factor in state security relations. However, it might have contributed to the destabilization of climatic security instead. Today, climate crises are affecting states in multiple ways and there is a developing census that it is becoming a key security threat to humanity. However, there is little understanding of how the maintenance of nuclear deterrence contributes to the climate crisis. There is the environmental impact of nuclear weapons tests, energy consumption for their development and maintenance, resource scarcity and allocation, and the issue of nuclear waste. More importantly, nuclear use means doomsday. Linking nuclear deterrence with climate change can increase public awareness about the interconnected risks of nuclear weapons and climate change. It also highlights the urgency and sensitivity of the risks. For human survival, it may need to choose between traditional security and climate security. While traditional security issues like the arms race, nuclear parity, non-proliferation and disarmament can be managed through dialogue, an uncontrolled climate crisis cannot be contained. Therefore, outreach and treaty advocacy should also focus on them through this lens. Moreover, nuclear disarmament treaties should incorporate climate considerations and divert resources to climate action.

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**P5.1 Synergies with Global Challenges** - Board: 16 / **P5.1-046**

## Regional Dispersion of Tephra from the Andean Volcanoes and Its Impact in Paraguay

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According to the scarce journalistic records, scientific reports and the testimony of some inhabitants in Paraguayan territory, volcanic activity in the Andes Mountain Range has had repercussions in Paraguayan territory. This refers to the dispersion of tephra originating from different volcanic conduits of the subduction zone type in the Pacific Ring of Fire located in the Chilean Andean belt, which, driven by the magnitudes of the eruptions and wind directions, traveled by advection in the atmosphere and arrived in Paraguay. This investigation highlights at least six events of this type: the eruption of the Calbuco volcano in 2015, of Puyehue in 2011, of Láscar in the years 2000 and 1993, of Quizapú in 1932, and of Cerro Blanco in the Holocene.

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## Cosmogenic Radionuclide for Civil Application: Be-7 and Application of Trans-Equatorial Method for Northeast Monsoon Forecasting in Malaysia

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The northeast monsoon (NEM) is an annual natural phenomenon in Malaysia, typically occurring from October to March. During this period, strong winds driven by two significant surges — the easterly surge and the meridional surge — bring heavy rainfall, often leading to severe flooding that can result in property damage and casualties. This study utilizes eight years of data (2011–2018) from International Monitoring System stations (IMS) alongside the Trans-equatorial technique to forecast the occurrence of NEM in Malaysia. A statistical approach incorporating data normalization and smoothing techniques was also evaluated to identify patterns in Be-7 measurements, which were then used as a reference for predicting the onset and withdrawal of the monsoon. By integrating IMS data with advanced processing techniques, the withdrawal of NEM in Malaysia was predicted with an accuracy of 341 days and a forecast horizon of ±7 days, achieving a correlation of 85%. However, the results for monsoon onset were less promising, indicating the need for further improvements to enhance forecasting accuracy. Although a strong correlation was observed for monsoon withdrawal, additional testing with more recent NEM seasons suggests that refinements are still required, particularly for improving monsoon onset predictions.

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## Harnessing Artificial Intelligence for confidence building and treaty verification in the CTBT framework: bridging technical innovation and science diplomacy

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How can Artificial Intelligence (AI) enhance the CTBT's verification regime and contribute to confidence-building among States Parties, while promoting science diplomacy to achieve universalization and entry into force? This paper explores the potential of Artificial Intelligence to revolutionize the Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification regime and foster international confidence-building. By enhancing detection capabilities, reducing false positives and streamlining data analysis, AI can address longstanding technical and political challenges that impede the Treaty's universalization and entry into force. Through the lens of science diplomacy, this study examines how AI-driven tools can reinforce the credibility of the International Monitoring System (IMS), strengthen the operational efficacy of On-Site Inspections (OSIs) and provide transparent data-sharing mechanisms to promote trust among States Parties. The integration of AI with the CTBT's verification framework not only exemplifies cutting-edge scientific collaboration but also highlights the interplay between technological innovation and the political will necessary for advancing global nuclear governance.

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## Decadal observations of deep ocean temperature change passively probed with acoustic waves

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The oceans are filled with acoustic waves, which are trapped in a low-velocity layer at about 1 km water depth. The sound speed of these waves strongly depends on the temperature. An increase in temperature will lead to an increase in the sound speed and hence shorter travel times. IMS hydroacoustic stations measure these waves continuously and travel times can be obtained through the cross correlation of transient signals between different hydrophones. IMS hydroacoustic station H10 near Ascension Island has been operational for nearly two decades. Although in place to detect nuclear-test explosion, H10 appeared well equipped to measure deep ocean temperature change. A decrease in the travel time between the two arrays was derived, being -0.002 s/yr. This corresponds to a deep ocean warming of 0.007 degC/yr, at about 900 m water depth. As such, acoustic waves provide an independent and passively acquired measure of the temperature increase in the deep ocean under climate change.

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## Environmental Variation Impacts on the International Monitoring System

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The International Monitoring System (IMS) is deployed at locations around the world, allowing for potential linkages to other data streams. One example of this is the correlation between radionuclide data and climate phenomena (e.g. monsoons). Due to the varying climate conditions, the IMS is well positioned to investigate potential signatures for climate change indicators through the detection of radionuclides. We have evaluated the correlation of IMS radionuclide data with climate change indicators near the IMS stations. Additionally, as these climate change indicators evolve with time, the impact on the IMS stations could impact future operation. We have evaluated the prediction of multiple climate change models on IMS stations to identify those most impacted by multiple climate change indicators such as flooding and typhoons. In this presentation, we will detail the work performed on correlating radionuclide data with climate change indictors at select IMS stations. Additionally, we will summarize the evaluation of potential climate change impacts to IMS stations.

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**P5.1 Synergies with Global Challenges** - Board: 20 / **P5.1-234**

## The 15th anniversary of the 'Tsunami Agreement' between UNESCO and CTBTO: reflections from the past and an outlook to the future

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The Tsunami Programme of the UNESCO-Intergovernmental Oceanographic Commission (UNESCO-IOC) coordinates tsunami warning and mitigation activities around the globe. As of today, 21 National Tsunami Warning Centres (NTWC) in 20 CTBT Signatory States benefit from the agreement between the CTBTO PrepCom and UNESCO allowing transmission of real-time IMS data to NTWCs recognized as such by UNESCO. In addition to the critical importance of the seismic data, there is a growing recognition of the value of the hydroacoustic and infrasound data for tsunami warning. Examples include the near-real time identification of the horizontal extent of the fault rupture, application of AI-based models to hydroacoustic data for rapid detection of tsunamis, monitoring of

volcanic explosions and ice shelf break-ups which may be of tsunamigenic potential. This presentation will provide an overview from the perspective of UNESCO-IOC on the progress made during the last 15 years within the framework of this agreement and will explore further synergies between the two organizations through joint capacity programmes with a special focus on developing countries and Small Islands Developing States (SIDS) towards provision of a sustainable framework addressing the needs of their NTWCs, where many of them are or can become a CTBTO National Data Centre.

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**P5.1 Synergies with Global Challenges** - Board: 21 / **P5.1-243**

## Real-time monitoring of global seismicity, response of the public and detection of particular seismic events

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The European-Mediterranean Seismological Centre (EMSC) monitors earthquakes on a global scale by merging the parametric data shared in real time by 113 networks; this represents almost 9 500 seismic stations, 5 million arrival times and 114 000 earthquakes (median location time: 15 minutes). The presence of the main global networks (e.g. NEIC, GEOFON, etc.) and numerous national networks among the contributors ensures exceptional coverage and detection levels, which are constantly being improved.
Thanks to their high visibility, EMSC information tools (websites, apps, social media bots, etc.) are natural focal points for witnesses seeking information after a widely felt tremor. This generates an immediate increase in usage, which can be automatically detected and its geographical origin determined. These 'crowdsourced detections' are fast (10 to 90 seconds) and their publication initiates the crowdsourcing of witness reports, which in turn contributes to rapid impact assessment. Sometimes, other types of seismic events are detected such as explosions, sonic booms or meteors. On 5 October 2024, within 30 minutes of the occurrence of an earthquake in Iran, a sudden increase in the number of visitors from Israel was detected, which for unclear reasons immediately led to online discussions about the possibility it was a nuclear test.

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## Analysis of Global Seismicity in 2024 and the Occurrence of Tsunamigenic Events Using the SSEB from the IDC of the CTBTO

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***The Standard Screened Event Bulletin (SSEB) from the IDC Product of the CTBTO*** provides a detailed and accurate record of global seismic activity, serving as a key tool for analyzing tectonic patterns and studying significant events. This study focuses on global seismicity recorded during the year 2024, ***emphasizing the identification of events with a magnitude greater than Mw: 4, potentially tsunamigenic, and their relationship with specific tectonic contexts.***

Parameters such as magnitude, hypocentral depth and epicentral location are analyzed using statistical software to generate frequency distributions, recurrence rates and occurrence probabilities. The analysis includes a classification of tsunamigenic events based on focal mechanisms and tectonic zones associated with subduction.

The results aim to establish statistical relationships that provide a better understanding of global risks related to seismicity and associated tsunamis, ***contributing to the development of disaster mitigation and preparedness strategies. This analysis highlights the importance of the SSEB as a data source for global seismic risk management.***

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## Effect of 2020 Taal volcano eruption on Lead-212 detection of CTBTO RN52 Station

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As part of its commitment to the Comprehensive Nuclear-Test-Ban Treaty (CTBT), the Philippines started the operation of its radionuclide station RN52 at Tanay in 2005 under the International Monitoring System (IMS). The station can detect not only anthropogenic radionuclides which may indicate existence of nuclear explosions, but also natural radionuclides such as Lead-212. Lead-212 is normally produced from the decay of Radon-220 emanating from the Earth's crust, but it can also be generated through volcanic eruptions due to the released magma. The increase in Lead-212 has been reported in past volcanic eruptions, such as the 2000 eruption of Miyake-jime volcano and 2004 eruption of Asama volcano which are both located in Japan. The Taal volcano, which is located approximately 70 km southwest of the RN52 Station, erupted on 12 January 2020 which may have released products containing Lead-212. In this study, the effect of the 2020 Taal volcano eruption on the Lead-212 detection of the RN52 Station was determined using statistical analysis and other relevant methods.

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**P5.1 Synergies with Global Challenges** - Board: 24 / **P5.1-284**

# International Monitoring System data contribution to the first building code in Bolivia (Plurinational State of)

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The Plurinational State of Bolivia has been striving to establish a seismic building code for over 12 years. While some building guidelines on 'how to build' were previously developed, they did not comprehensively address critical aspects related to seismic hazard. Although Bolivia experiences moderate seismic activity, destructive earthquakes have occurred with recurrence intervals of approximately 30 to 50 years, the most recent being in 1998. The rapid urban expansion of cities such as La Paz, Cochabamba and Santa Cruz has intensified the demand from national and municipal authorities for a unified seismic building code. In response, the Observatorio San Calixto presented a probabilistic seismic hazard map for Bolivia, demonstrating that high-quality data from IMS stations enabled the calibration of magnitudes within the seismic catalog and provided essential raw data for developing seismic design spectra for new buildings. For the first time, in November 2023, the seismic building code was officially approved by the Ministerio de Obras Públicas y Vivienda of the Bolivian government, marking a significant milestone in the country's efforts to enhance earthquake resilience.

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# Monitoring of high-mountain glaciers in the territory of Tien-Shan by stations of the International Monitoring System

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At KNDC, data from Makanchi's PS23 array revealed a large number of similar events with sources in the area of large glaciers in Tien-Shan. All events are in the 185-190 back-azimuth range at a distance of 550 km south of the station. The size of the epicentre area were about 90x90 km. Daily and seasonal variations in the number of events recorded were revealed, and their energy and magnitude was estimated.
At the end of 2023, three seismic and one infrasound stations were installed near glaciers on the Kazakh side to study the impact of climate change on the cryosphere. Seismo-acoustic recording will be carried out during 2023-2028. All seismic stations record well the events associated with processes in the glaciers. Data processing has been carried out and a seismic event bulletin has been compiled. Event magnitudes are mb≤3.5, energy classes K≤8.4. The possibility of studying glaciers

remotely using permanent seismic and infrasound stations is shown. The data of seismic arrays for 20 years of observations are processed by the PMCC to search for regularities of seismic processes in glaciers related to climate change and to compare them with the results of studying the state of glaciation of Tien-Shan glaciers by different technologies.

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## Seismic Hazard Analysis for the Central Plain of Thailand

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A study examined seismic hazard in Thailand's central plain, characterized by a thick quaternary basin. Unconsolidated sediments may amplify seismic ground shaking, potentially increasing structural damage. The research resulted in a fundamental frequency map derived from HVSR analyses at 149 microtremor sites. A Vs30 map was subsequently generated using HVSR inversion methods, alongside a soil classification map based on NEHRP standards. The upper central plain near the Yom and Nan Rivers demonstrated a low fundamental frequency of 0.3-0.5 Hz and low Vs30, categorizing it as soil type Class E. In southern Ayutthaya, Pathum Thani and central Bangkok, an extremely low Vs30 below 100 m/s suggested soil class F or special soft soil. A thorough probabilistic seismic hazard analysis was performed, considering Vs30 conditions. The northern upper central plain and western central basin showed relatively high seismic hazards. Additionally, site effects notably amplified ground motion at the 1.0 second period, exceeding Thailand's earthquake-resistant design standards by over five times, particularly in the central lower plain region.

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## Occurrence of earthquake in the vicinity of Bangladesh from 2001-2024: Implications for disaster management and preparedness

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Earthquake is one of the foremost disasters which cause severe disruption of life and property. In Bangladesh, earthquake is considered as hidden disaster as the country is tectonically located at the junction of three tectonic plates (Eurasian, Burma and Indian plate). To understand the potential risks of the deadly catastrophe in Bangladesh, an earthquake distribution map was prepared using earthquake occurrence data of the last two decades from the United States Geological Survey (USGS) Earthquake Catalogue. In the present study, earthquakes of 3.5 or above magnitude were considered, which caused significant seismic activity in and around Bangladesh. During the above-mentioned period, more than 600 earthquakes were recorded, among them approximately 98% of the earthquakes are below 5.5 magnitude. However, there are at least 14 earthquakes of more than 5.5 magnitude which were felt quite noticeably with record of human casualties, fractures of buildings, dropping of materials, etc. From these recent EQ occurrence data, the Eastern part of Bangladesh is identified as the earthquake prone area where higher magnitude earthquake frequency also increased in recent time. These data will contribute to different awareness raising activities of Department of Environmental Science and Disaster Management, DIU in collaboration with CTBTO NDC-BD.

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## Interpretation of Bolide infrasonic observation on 25 August 2024 in South Africa

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On 25 August 2024, around 6h50 UT, Bolide impacted the Earth atmosphere over South Africa. This event was recorded at some IMS infrasound arrays in Southern Africa. Data analysis were performed using GTK-PMCC software (CTBTO) based on PMCC method (Y. Cansi 1995). A pass-band frequency between 0.1 Hz and 4 Hz is applied to detect the source. As results from infrasound station I47ZA, azimuth is around 180° for the coming infrasound signals. Infrasound processing gave an estimated energy of 0.09 kT. Acoustic simulation of propagation using Raytracing technique (Virieux, 2004 Hamiltonian mathod ; Bass & Sutherland, 2003 absorption model) shows dominant stratospheric phases.

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## Operational Applications of Atmospheric and Oceanic Diffusion Modeling at RSMC Beijing

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RSMC Beijing became one of the world's eight Regional Environmental Emergency Response Centers by the end of 1996. Since 1997, it has provided nuclear incident response exercises for the IAEA under the WMO framework and has offered source reconstruction services for CTBTO's IMS monitoring stations since 2003. The center's current environmental emergency response system is based on China's CMA-GFS and CMA-MESO numerical weather prediction models, and the HYSPLIT and CMA-SDM Lagrangian atmospheric diffusion models. These models form a multi-scale atmospheric diffusion forecasting system, supporting forecasts from minutes to weeks and addressing diverse emergency response needs. Key technologies include source term assessment for nuclear plants, ensemble forecasting for medium- and large-scale diffusion, multi-trajectory source reconstruction and dose assessment, which have been applied in incidents such as the Fukushima disaster and national nuclear emergency exercises. A rapid-response platform has been developed, integrating data management, diffusion model computation and product distribution, enabling full automation from data processing to product release. Future efforts will focus on next-generation MCV-based diffusion systems and further development of source term and assimilation technologies.

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## Integrating IMS and NDC Into the National Nuclear and Radiological Emergency Response Plan to Enhance Radiological Emergency Response in Nigeria

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The National Nuclear and Radiological Emergency Plan (NNREP) outlines Nigeria's strategy for a coordinated and timely response to radiation emergencies, integrating local, national and international efforts to protect public and worker safety. The CTBTO's International Monitoring System (IMS) and International Data Centre (IDC) provide advanced technologies and data for detecting nuclear explosions, with potential applications for civil and scientific purposes. This work aims to integrate the CTBTO IMS and IDC into the NNREP, alongside other national and international agencies, to enhance emergency response capabilities. Such integration would significantly improve public health and safety measures in Nigeria and is a feasible objective.

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# XENAS: An overview of environmental radionuclide monitoring of pressurised water reactor

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As part of the Xenon and Environmental Radionuclide Analysis at Sizewell (XENAS) experimental campaign, a UK-based Pressurised Water Reactor (PWR) nuclear power station (Sizewell B) has provided access allowing measurement of several radionuclide monitoring process routes. This work aims to provide an overview of the experiment, discuss its motivations, present the results obtained to date and outline its future direction. Measurement campaigns such as this provide useful insight for the nuclear explosion monitoring community and supplement the existing characterisation of sources of manmade radionuclides relevant to the Comprehensive Nuclear-Test-Ban Treaty (CTBT).

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# Blowing on the Wind: eDNA Profiles from CTBTO Air Filters to Monitor Biodiversity

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The CTBTO maintains a global network of monitoring stations with air filtering equipment to detect radionucleotide signatures. These air filters also pick up plant, animal and microbial DNA that has been scattered on the wind. This environmental DNA (eDNA) can be profiled to catalogue species, providing the opportunity to monitor ecosystem changes and track biodiversity at an unprecedented scale, including the presence/absence of invasive, pest and endangered species.

Twenty-one daily air samples were collected on filters on the rooftop of the CTBTO building in Vienna. Here, we describe optimisation of laboratory methods to extract and amplify DNA from these filters and then catalogue biodiversity via high-throughput sequencing.

We detected eDNA from a wide range of species including plants, arthropods, mammals and birds. This included many species expected to be present in the wider Vienna region, but not in New Zealand where the laboratory work was conducted, validating that the eDNA profiles were recovered from the air filters themselves.

To the best of our knowledge, this is the first time that CTBTO air filters have been used for eDNA profiling and demonstrates that they offer a valuable resource for biodiversity monitoring across large geographic and temporal scales.

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## The Necessity of Infrasound Stations for Comprehensive Monitoring in Indonesia

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This study assesses the need for an infrasound station facility in Indonesia, with Ujung Kulon, West Java as one of the potential sites. Indonesia relies on infrasound data from nearby countries limiting independent monitoring of detail events. Data from IMS stations like I06AU, I39PW and others provide insights, however are insufficient for comprehensive monitoring.

The installation of an infrasound station at Ujung Kulon will enhance the national Early Warning System (EWS) in Indonesia, complementing the seismic network and improving disaster forecasting and climate monitoring. A temporary infrasound station was installed by BMKG in Palangkaraya, Kalimantan in 2004 with support from DASE/CEA, but it is no longer operational, highlighting the need for permanent infrastructure.

This study proposed a distributed infrasound array model for the initial station installation, which would eventually expand to strategically selected places throughout Indonesia. This array design optimizes data collecting by assuring wider coverage, increasing signal detection sensitivity and minimizing noise interference from ambient factors.

Infrasound technology is useful for detecting low-frequency acoustic waves from volcanic eruptions, tsunamis and atmospheric disturbances, often overlooked by seismic systems. Establishing in-country infrasound stations will strengthen Indonesia's monitoring capacity, enhance disaster preparedness and contribute to global networks.

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## Imaging lava eruptions and crater morphology changes at a basaltic volcano using infrasound

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Eruptions at continental basaltic volcanoes, the dominant mode of volcanism on Earth, can take and combine various forms, including lava lake, lava flows and fountaining, explosions or structural collapses. Aside from a few well-instrumented cases, accurately reconstructing their precise processes and chronology is hampered by the lack of detailed visual observations in space and time. However, because they emit infrasounds, any changing and potentially hazardous eruptive activity can be inferred with specialised microphones. At Nyiragongo volcano (D.R. Congo), its flank eruption in 2021 was accompanied by the drainage of the world's largest lava lake modifying the acoustic resonance of the summit pit crater. Too low to be perceived by human ears, the excitation of resonance frequencies were recorded from local distance (0-20 km) up to Kenya (~800 km) and are interpreted in terms of the time-varying pit-crater geometry using acoustic numerical modelling. We also tracked lava fountaining and flows on Nyiragongo's flank by means of the emitted infrasound to get a consistent scenario of lava movements between crater and flank. This remarkable acoustic signature thus encoded the underlying mechanisms of a rare flank eruption, which could help to anticipate the next one.

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## The Psychological Impact of Nuclear Weapons Proliferation on Global Populations

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This study examines the profound psychological effects of nuclear weapons proliferation on global populations. The constant threat of nuclear conflict creates a pervasive sense of fear and anxiety, impacting mental health and societal stability. Historical instances, such as the Cold War, highlight the long-term psychological stress experienced by individuals living under the shadow of potential nuclear war. The research utilizes data from various psychological studies and surveys to analyze the correlation between nuclear threat perception and mental health issues. Findings underscore the need for international efforts to reduce nuclear arsenals and promote peace to alleviate the psychological burden on global populations.

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**P5.1 Synergies with Global Challenges** - Board: 37 / **P5.1-581**

## Tsunami Wave Height Modelling Using COMCOT Software 3 Based on Maximum Earthquake Scenario in Bali Island

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Bali Island is one of the areas in Indonesia that is categorised as a tsunami-prone area due to the existence of the Java Megathrust in the southern segment of Bali, which holds a maximum magnitude of up to M 9.0, which can trigger a tsunami. This study aims to model tsunami wave heights and wave arrival times based on the maximum earthquake scenario in the southern Bali megathrust zone. The modelling is done using COMCOT (Cornell Multi-grid Coupled Tsunami Model) software. The data used in the tsunami modelling consists of earthquake parameter data from the Global CMT Catalogue, as well as bathymetry and topographic data from GEBCO, BATNAS and DEMNAS. The simulation results show that the tsunami generated can reach a maximum height of up to 18 metres in southern Bali. From the tide gauge points that have been made, the point located at the Nusa Penida location shows a maximum amplitude of up to 5 metres. In addition, the simulation of tsunami wave propagation also shows that the waves take about 15-20 minutes to reach the mainland of the south coast of Bali and Nusa Penida after an earthquake.

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# WMO's Role in Nuclear Emergency Response and Cooperation with CTBTO

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The World Meteorological Organization (WMO) supports its Members and related international organizations such as the IAEA and the CTBTO regarding nuclear incidents and accidents and the determination of possible source regions related to anomalous, treaty-relevant radionuclide measurements. To respond to nuclear emergencies 24/7, Ten WMO Members WMO Integrated Processing and Prediction System Designated Centres (WIPPS-DCs) to cover the entire globe.

Within the framework of the cooperation agreement between the Preparatory Commission for the CTBTO and the WMO, the Provisional Technical Secretariat (PTS) notifies both the WIPPS-DCs for the provision of atmospheric backward transport and dispersion products and the WMO Secretariat in the event that anomalous radionuclide measurements occur in the International Monitoring System. The notification message contains a list of radionuclide station locations for which products are requested. The products are uploaded to a secured FTP server, as defined in the request form, within 24 hours of reception and according to the pre-agreed format and conditions. This working arrangement is outlined in the Manual on WIPPS (WMO No. 485).

WMO emergency response activities are coordinated by an expert team. In 2024, the team agreed to provide higher-resolution products in both time and space and to include noble gases for tracing.

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# Promoting the Peaceful Use of IMS Data for Climate Research and Climate Change Monitoring

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) processes data from the International Monitoring System (IMS), which, though primarily used for nuclear explosion detection, also has valuable applications in scientific and civil domains. As the effects of climate change become more evident each day, it is crucial to keep the topic alive and continue exploring ways IMS data can contribute to climate research. IMS technologies provide insights into climate change by monitoring indicators, validating models and studying Earth's systems, showcasing their potential to enhance climate studies.
Additionally, using IMS data for climate research helps refine calibration and data analysis techniques, improving the precision of both nuclear and climate-related data. Building upon these foundations, the research suggests further integration of IMS data into climate monitoring, offering crucial insights to inform global strategies for mitigating and adapting to climate change. Continued use of IMS data not only supports climate research but also strengthens the scientific community's ability to safeguard the planet. Ultimately, the research underscores the importance of maintaining climate change as a priority in global discussions and leveraging innovative solutions to address this critical issue.

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# On the use of Be-7 observations to study atmospheric processes

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The International Monitoring System (IMS) offers a vast amount of data that can advance scientific research beyond treaty verification. Here, observations of beryllium-7 (Be-7) that are made by particulate radionuclide IMS stations are considered to study atmospheric processes. Be-7 is a cosmogenic radionuclide that is produced mainly in the upper troposphere and lower stratosphere. Near-ground Be-7 concentrations are governed by several atmospheric processes, including deposition and downward advection. Observed variations in the Be-7 concentration allows to study these processes.
Here, a backward-in-time modelling approach is proposed using the Lagrangian particle dispersion model FLEXPART. The model allows to explain observed peak concentrations of Be-7 by linking these observations with specific weather events such as stratosphere-to-troposphere exchange. Examples will be provided, including a case where stratosphere-to-troposphere exchange was facilitated by a cut-off low. A better understanding of stratosphere-troposphere processes is of particular

interest as it allows for extended-range weather forecasting, which is of high interest for several applications, including agriculture and the energy market.

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## The Importance of CTBTO Data in Climate Change Research

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) operates an advanced network system of the International Monitoring System (IMS) designed to detect nuclear explosions. Beyond its primary mission, the IMS's network of seismic, infrasound, hydroacoustic, and radionuclide stations provides invaluable data that can be used by researchers for climate change studies. This presentation explores how CTBTO data has been invaluable and enhanced climate models and support the study of climate change impacts.

IMS data offers real-time insights into atmospheric and environmental processes. Radionuclide data tracks greenhouse gases, pollutants and aerosols, revealing their global distribution. Infrasound and seismic data contribute to understanding atmosphere-ocean interactions, such as tsunamis and volcanic eruptions, which affect climate patterns. Hydroacoustic data informs ocean temperature dynamics, a key indicator of global warming.

These datasets validate climate models, predict weather events and study long-term human activity impacts. They also foster interdisciplinary collaboration across geophysics, environmental science and meteorology. The accessibility and reliability of IMS data provide researchers with a robust framework to address climate challenges.

Leveraging data initially intended for nuclear monitoring highlights the importance of international cooperation and data sharing. As climate challenges escalate, CTBTO data remains a critical resource for developing sustainable, global solutions.

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## Leveraging competencies and expertise across international organizations in support of global peace and security

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The Chemical Weapons Convention and the Comprehensive Nuclear-Test-Ban Treaty were both adopted in the early to mid-1990's, a time of renewed hope for global disarmament and non-proliferation efforts. In the decades since, both implementing organizations for these instruments – the Organisation for the Prohibition of Chemical Weapons (OPCW) and the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) – have worked tirelessly to prepare for/ensure the effective implementation of their respective mandates. While these mandates and associated responsibilities vary between organizations, there are significant areas of potential cooperation and collaboration that can help promote global peace and security by leveraging the wide-ranging competencies and expertise built up by these and other organizations over the years. One such example is the OPCW's implementation of a project, under the framework of the United Nations Global Counter-Terrorism Coordination Compact, to enhance interagency interoperability and public communications in the event of a chemical or biological attack, during which CTBTO representatives participated in workshops on emergency response/operations centres and deployments. What lessons can we learn from these interactions and what further opportunities exist to foster effective collaboration among relevant organizations in support of their mandates?

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## 2011-2020: A decade of global volcanic events observations at the IMS infrasound network

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The Global Volcanism Program (GVP) includes comprehensive list of the 1281 Earth's active volcanoes and their eruptions over the last 12,000 years. In this work, we used the web-based GVP database of the Smithsonian Institute to correlate detections from the International Monitoring System (IMS) infrasound network in the period 2011-2020. According to GVP data, 360 eruptions (or confirmed eruptive activity) occurred from 138 volcanoes. Among those, we selected 79 confirmed eruptions originated from 47 volcanoes with Volcanic Explosive Index (VEI)>3: 64 events were ranked with VEI=3, 14 events with VEI=4 and 1 event with 1 VEI=5. Data from 44 IMS infrasound stations were processed and analysed in the specified time window using the Progressive Multi-Channel Correlation (PMCC) algorithm. A station-to-source back-azimuth deviation of 5° and 10° was considered, using a cross-bearing azimuth methodology. We present here that the IMS network infrasound detections show correlation with the selected volcanic events. We present as well the correlation of the volcanic events with the events listed in the Latest Events Bulletin (LEB), Standard Event Lists (SEL3) and Reviewed Event Bulletin (REB) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) International Data Centre (IDC).

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# CTBTO in the Face of Climate Change and Natural Disasters: How to Adapt

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) faces evolving challenges in its mission to monitor and verify nuclear-test-ban compliance due to the intensifying effects of climate change and the increasing frequency of severe natural disasters. The CTBTO's International Monitoring System (IMS) must now contend with heightened environmental noise, data anomalies and system vulnerabilities caused by climate-driven disruptions. Rising sea levels, extreme weather events and shifting atmospheric conditions can complicate the interpretation of monitoring data, leading to potential ambiguities in distinguishing between natural and anthropogenic phenomena. Furthermore, damage to monitoring stations from disasters such as earthquakes, tsunamis and hurricanes can temporarily compromise network integrity, delaying critical evaluations. These challenges necessitate innovative approaches to data analysis, enhanced station resilience and robust protocols for disaster recovery. This paper wishes to underscore the imperative for the CTBTO to adapt its systems and methodologies to ensure the continued accuracy and reliability of its global monitoring efforts in an era of environmental uncertainty. By addressing these issues, the CTBTO can maintain its vital role in promoting international security and nuclear non-proliferation amidst the challenges posed by a changing planet.

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**Online e-Poster Session 2** - Board: 0 / **P5.1-746**

# The Role of CTBTO in Global Climate Change Governance: Prospects for the Pacific Island States

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Global Climate Governance is an emerging arena of policy-making with the primary objective of formulating practical alternatives to deal with the adverse consequences of climate change along with creating an agile mechanism that is adequate from a scientific perspective and also encourages universal participation. Countries are experiencing frequent natural disasters due to climate change, particularly in small island states where sea level rise is endangering whole communities and means of subsistence. The CTBT has been signed and ratified by several Pacific Islands states, the most recent additions are Solomon Islands and Tuvalu. CTBTO's substantial long-term engagement and capacity-building initiatives could better assist these small island states in the Pacific to deal with climate change. The paper intends to highlight two verticals. Firstly, the paper will navigate the emerging role of the CTBTO in the context of Global Climate Change Governance and reflect on how the CTBTO is going to play a significant role in capacity-building measures in the Pacific Island Nations to deal with the effects of climate change. Secondly, the paper will highlight how this would help CTBTO to foster multilateral partnerships with developing nations and become a bridge between the global south and the global north.

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**P5.1 Synergies with Global Challenges** - Board: 46 / **P5.1-755**

## Global Climate Governance: Navigating the Prospects of CTBTO in Multilateral Climate Cooperation

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Climate change is a matter of both geopolitical and regional concern. In order to address it comprehensively, Global Climate governance is a crucial issue that requires both scientific and practical attention. Climate change governance is an emerging domain that has a complex relationship with public and state administrative structures. In recent times the Comprehensive Nuclear-Test-Ban Treaty Organization is not only acting as a powerful instrument to protect our planet from the devastating effects of nuclear explosions but it also has the potential to advance scientific research, sustainable development and human welfare through its innovative systems. In recent years, challenges from climate change have become increasingly significant. The CTBTO global alarm system might help institutionalize global climate change governance. The proposed paper intends to highlight two fundamental verticals. Firstly, the paper will contextualize the notion of Global Climate Change Governance and its evolving significance in contemporary world affairs. Secondly, the paper will discuss how, in addition to its traditional function as a global regulator on nuclear non-proliferation, the Comprehensive Nuclear-Test-Ban Treaty may serve an instrumental role in the domain of multilateral climate cooperation and transform and further solidify its position in international negotiations on action against climate change.

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## Radionuclide Detection Variation in Europe: A Comparative Analysis Using RNToolkit

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This study examines the evolution of radionuclide detections over time at eight stations within the CTBTO IMS network: SEP63 and SEX63 (Stockholm, Sweden), RUP61 and RUX61 (Dubna, Russian Federation), DEP33 and DEX33 (Schauinsland, Germany), and NOP49 and NOX49 (Spitsbergen, Norway). Data covering the period of 2021 to 2024 were analysed and compared using the RNToolkit software. The assessment focused on identifying potential changes in radioactivity levels — encompassing particulates and noble gases — that could be attributed to human activities, nuclear incidents or changes in the atmospheric transport of radionuclides.
Preliminary findings suggest that the observed increase in detected events may be linked to unintentional emissions from nuclear facilities or to the intensification of industrial and commercial nuclear activities in Europe. This study underscores the critical role of the CTBTO monitoring network in understanding the global environmental implications of anthropogenic activities. Additionally, it highlights the importance of enhancing detection capabilities of the IMS.

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## Tackling Trust in the Treaty: New Technologies and Diplomatic Strategies to Build Confidence in the CTBT(O)

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Nearly three decades since the establishment of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), rapid developments in artificial intelligence (AI), autonomous systems, and global communication and data networks are radically changing the technological landscape in which the CTBTO operates. Concurrently, geopolitical conflicts have impacted states' trust in international institutions and their capacity to deter non-compliant states. Is the current form of the CTBT suited to address these evolving conditions? Moreover, is the CTBTO able to fulfill its objective of monitoring and deterring nuclear testing, while bolstering support from existing and potential Member States?
As open-source satellite imagery has revealed a renewed drive for nuclear testing in Nuclear Weapon States, we will explore how the CTBTO must expand its technological means to build trust and shift political strategies to empower Non-Nuclear Weapon States in uncertain geopolitical conditions. This includes assessing shortcomings present in current methods to address and respond to contemporary technical and political conditions that affect the evolution of nuclear warfare. This presentation will discuss the importance of developing a political trust-building strategy based on inclusive diplomatic outreach and effective technological methods to maximise the CTBTO's success in an increasingly multi-polar geopolitical environment

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# Nuclear Explosions, GIS and Utilizing an Interdisciplinary Approach to Understanding Environmental Impacts

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Nuclear explosions have enormous environmental impacts on the planet and its systems, which intersect with climate change in a variety of ways. Analogous to climate change, these impacts and their social repercussions are unequally distributed. The importance of education, effective science communication and an intersectional social understanding are paramount to building public awareness.
Geographic Information Science (GIS) is used to illustrate both physical and social trends spatially. It offers a way to visualize the effects of wildfire burn, to map invasive species or to understand healthcare accessibility across neighbourhoods, among others.
GIS offers a way to visualize the ecological hazards of nuclear explosions and testing, providing materials that can be used for outreach, education and communication. Possibilities include mapping the extent of ecological damage near testing sites or spatial distribution of hydrological effects. GIS also offers the opportunity to visually represent the social impacts across communities, from disproportionate health outcomes to agricultural damage.
This poster aims to illustrate the importance of spatial representation in providing a meaningful, nuanced perspective to nuclear testing and its environmental impacts. Utilizing an interdisciplinary lens is critical to analyzing and understanding the magnitude of impact and the disproportionate burden nuclear testing places on vulnerable communities.

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# Analysis of infrasound generated by the meteoroid explosion over Japan on 29 November 2020

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The explosive fragmentation of large meteoroids is one of the most significant sources of infrasonic waves. In the absence of atmospheric nuclear tests since 1980, bolide explosions have become key infrasound sources for calibrating and testing the instrument sensitivity of the International Monitoring System (IMS). Moreover, detecting meteoroid explosions with infrasound arrays is crucial for estimating their potential impact and frequency of occurrence. To evaluate the sensitivity of IMS instruments, we applied the Progressive Multi-Channel Correlation (PMCC) method to the infrasound records generated by the meteoroid explosion over Japan on 29 November 2020. Reliable results were obtained for only two stations located at approximately 412 km (Japan) and 1238 km (Russia). The triangulation of both stations was used to locate the infrasound source near Shingu, in Wakayma Prefecture, Japan. The eyewitness reports also corroborate the estimated location. The meteoroid explosion had a yield of less than 1 kiloton TNT, indicating that the IMS network is capable of detecting infrasound events with very low yields.

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## Assessment of Hypocenter Accuration and Dissemination Performance of Indonesia Tsunami Eraly Warning System (INATEWS)

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In this study, we present the assessment of the hypocenter location and the dissemination information in the Indonesia Tsunamy Early Warning system (INATEWS), Indonesia. The determination of accurate hypocentral parameters is crucial in seismic monitoring and early warning. In this study, we present the earthquake parameters computed by SeiscomP from the January 2020 to December 2024 scale for events with magnitude M 2.5, and the detection timeline. From our analysis the epicenter location generally differs less than 25 km from the final epicenter coordinates; focal depths are less well constrained and differ generally less than 20 km. The assessment of the magnitude shows significant differences with respect to the magnitude based on final catalogs. Our study result shows that the epicenter coordinates and the magnitude values converge rather quickly toward the final values. Generally, BMKG (Agency for Meteorology Climatology and Geophysics) can provide reliable information of the earthquake source parameters less than 3 minutes and disseminate tsunami warning message within less than 10 minutes after origin time.

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## Growth and advancement of the Seismology Laboratory at the National Data Center of Paraguay

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The Seismology Laboratory of Paraguay originated from a bilateral agreement between Paraguay and the United States, through the United States Geological Survey (USGS), in the early 1990s. This agreement enabled the installation of a broadband seismological sensor and a short period sensor. Years later, Paraguay signed and ratified the Comprehensive Nuclear-Test-Ban Treaty (CTBT), which led to the installation of an infrasound monitoring station. Since then, we have been in constant training on operations and data analysis, significantly improving Paraguay's analytical capacity and equipment. Thanks to these advancements, the Seismology Laboratory, located in the Faculty of Exact and Natural Sciences, transitioned from operating with a single seismological sensor and a basic software called SEATool to having a server, more robust analysis software, access to data from the International Data Centre and the capability to conduct both seismic and infrasound analyses. This development has significantly strengthened the laboratory's ability to monitor and analyse both seismic and infrasound events on a national and international level.

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## Analyse data in the NDC of Congo by GPMCC and Geotool

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To help make visible the National Data Centre (NDC) in Congo Brazzaville, we will share the experience on the daily work of the NDC, including the way to analyse data with the NDC in a box software, with an example of an explosion of an ammunition depot on 4 March 2012 in a military camp in Congo Brazzaville:
- Their missions,
- Their analysis technique,
- Conclusions.

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## Strengthening Latin American and Caribbean engagement in CTBTO technical, scientific and diplomatic arenas

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The Latin American and Caribbean (LAC) region has demonstrated a strong commitment to the Comprehensive Nuclear-Test-Ban Treaty (CTBT), actively supporting its nuclear disarmament and non-proliferation objectives. However, the participation of LAC experts in critical Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) meetings, especially in Working Group B focused on technical and scientific aspects, remains remarkably low. This presentation addresses barriers that limit LAC participation, such as small groups involved in CTBT issues, communication at the national level and financial barriers, among others. To overcome these gaps, we propose to create synergies among LAC countries and establish regional representatives, not only from the diplomatic sphere but also specialized technicians and the scientific community. To this end, work has recently been done to create a visual profile for each LAC country, illustrating its specific relationship with the CTBTO and highlighting opportunities for strengthening it in a visual and accessible way. Increasing LAC representation not only diversifies perspectives within the CTBTO but also strengthens regional contributions to global monitoring and verification efforts, thus promoting an inclusive and resilient framework for a nuclear test-free world.

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## The role of Nigeria's NDC to research revolution in Nigeria: A Scientist's perspective

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National Data Centers (NDCs) play various roles, such as organizing capacity building events for a critical mass of interested States Signatories of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), sensitizing the public on the danger of a nuclear explosion, providing International Monitoring System (IMS) data, International Data Centre (IDC) products for research and other purposes. Nigerian female university students and researchers now know more about the CTBTO and have conducted more research related to nuclear monitoring thanks to NDC-NG's initiative to raise awareness for female scientists and engineers in developing their research skills using IMS data, IDC products and science diplomacy. As a beneficiary, the purpose of this work is to demonstrate my knowledge and proficiency, particularly concerning the scientific and civil applications of the CTBT, and present findings from analysis of seismic and infrasound data acquired from IMS stations. For the first time, I used Geotool software to determine several seismic events' locations, magnitudes and depths. DTK PMCC software was also used to calculate azimuth, apparent velocities, errors and other significant parameters from infrasound signals. Since the initiative's launch in 2020, research conducted by female students and early career scientists in Nigeria using CTBTO's data and products has increased significantly.

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# Difficulty to implement radiological monitoring in air in Mali

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Mali is a landlocked country in West Africa. It is the eighth largest country in Africa, with an area of over 1 241 228 km2. The country is bordered by Algeria, Niger, Mauritania, Burkina Faso, Ivory Coast, Guinea Conakry and Senegal. Mali is a Sahelian country with a tropical and dry climate. Strong winds that blow during the seasons generate aerosols in the air. Depending on the meteorological conditions, these aerosols can travel several miles before being deposited somewhere. Mali is a State Signatory of the Comprehensive Nuclear-Test-Ban Treaty (convention signed in 1997 and ratified in 1999). Based on that convention, it has established its Regulatory Body in terms of radiation protection, called in French AMARAP. AMARAP has implemented a monitoring programme of the environment with the main objective of putting under regulatory control air, water, soil and foodstuffs. That programme has started by establishing the radiological map (background level of natural radioactivity), acquisition of gamma spectrometry detectors (portable and fixed). Soil, foodstuffs and water analysis by gamma spectrometry have been carried out for some localities. There are still some difficulties in starting radiological monitoring in the air. This paper (document) will explain the achievements and expectations for implementing the efficient monitoring of the environment in Mali.

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# Angolan National Arms Control and Disarmament Authority (ANCAD) framework for implementing the Treaty

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The present summary is a small contribution of the National Authority for Arms Control and Disarmament (ANCAD) to the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) Science and Technology Conference. This work is intended to be the beginning of the development of ANCAD research in the area of monitoring technologies linked to CTBTO. Within the scope of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), the work includes monitoring seismology data (seismic profile of Angola), recent events and ANCAD's experience in installing the National Data Centre (NDC) in Angola. We believe that this work will promote global security and contribute to the implementation of confidence building measures recommended by the Treaty. In this paper, we present a case study of event detection, classification and interpretation of data obtained at the National Data Center. In this work, we present initial results of the detection and localization of

seismic analysis of seismic waves recently obtained at the NDC. We believe that this work will provide a greater understanding of the implementation status of the CTBT and reinforce the existing measures for the implementation of the same Treaty taken by ANCAD.

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## Advances in nuclear monitoring and Earth science research by NDCs in Africa: The West African model

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The majority of the issues that have hindered West African National Data Centers (NDCs) ability to carry out complementary nuclear explosion monitoring (NEM) functions and fill critical research gaps are being gradually resolved through the utilization of International Monitoring System (IMS) data, International Data Centre (IDC) products and the Comprehensive Nuclear-Test-Ban Treaty Organization capacity building programmes. Our recent findings from improved complementary NEM using data from IMS/Auxillary stations (PS15, IS17, AS97, IS11, AS62, PS26, AS34, PS11, IA12, IS50 and HA10) covering fifteen years are presented in this research. Geotool, SeisComP and TDK PMCC software were used for data processing and analysis. Results from earthquake analysis (locations, magnitudes and depths) confirmed the recent rise in seismicity in the studied area by clearly identifying the alignment of earthquake epicenters connecting suture zones to coastal regions of West Africa. T phases, which are linked to underwater volcanic or seismic events, were identified from the hydroacoustic signals. Back azimuths and apparent velocities were also determined from the infrasound signals, which helped establish the direction of the events. We achieved a significant feat in this work by using the three waveform technologies of the Comprehensive Nuclear-Test-Ban Treaty to construct a detailed event chronology and bridged major research gaps in the study area.

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## Hydroacoustic activities detected in the Indian Ocean during the global outbreak of the COVID-19 pandemic

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This paper describes the result of hydroacoustic data processing using the Comprehensive Nuclear-Test-Ban Treaty Organization's hydrophones HO1W, HO8S and HO4N during the period between 2018 and 2020 by the National Data Centre (NDC) in Madagascar. The main objective is to apply and follow the recommended steps described by the Provisional Technical Secretariat at the NDC forum website (https://ndc-forum.ctbto.org/t/how-to-process-hydroacoustic-data-in-ndc-in-a-box). We use the PMCC method for data processing with the described detection parameters on the website. During the entire period, detections were continuously observed between azimuth 140 and 250 for HO1W, between azimuth 27 to 35 for HO8S and between azimuth 150 to 200 for HO4N. In addition, we observed signatures of earthquakes along the Indian Ocean Ridge, as well as the Tsunami generated after the Krakatoa volcano eruption on 22 December 2018, ice breaking, and other events. Associating the arrival at the event location is one of the challenges we faced during this study. Consequently, detecting signatures of life below water needs further analysis and experience. We managed to follow and apply the recommended ways to process hydroacoustic data from the International Monitoring System.

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## Automated Multilingual Seismic Event Reporting Module for SeisComP Pipeline Based on Python for NDCs

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This work presents the result of developing a customized and innovative tool for National Data Centers (NDCs), based on Python. This tool automates the creation and sending of seismic event reports, enhancing the efficiency and speed of critical data communication, allowing the generation of information in multiple languages. It provides a flexible and adaptable tool to specific needs of each NDC, fostering cooperation and knowledge exchange, and supporting the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The module generates reports adaptable to the needs of each NDC, using web technologies like HTML5 and CSS for functional design. A key feature is the configuration of the geographic window of the area of interest using GMT, allowing precise customization. Additionally, the system includes parameterization and automatic report generation, facilitating relevant information collection and presentation without manual intervention once events are detected by SeisComP. Reports are automatically disseminated to authorized users through multiple channels, including email and Telegram, ensuring quick and effective data distribution. This development optimizes operational processes within NDCs for nuclear event detection and strengthens response capabilities to seismic events. It improves the efficiency of information management and decision making during emergencies, while promoting cooperation and knowledge exchange, thereby reinforcing support for the CTBT.

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# International cooperation in seismic monitoring across the Arabian Peninsula

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Increasing urban development combined with damage from recent earthquakes highlights the need for resilient infrastructure and a better understanding of seismic hazard. During the past several decades, the expansion of national seismic networks and data collection in the Middle East has improved seismic monitoring and contributed to emergency preparedness and response. Lawrence Livermore National Laboratory (LLNL), through the US Department of Energy's Seismic Cooperation Program (SCP), supports joint research and high quality data collection in collaboration with international partners in the Middle East. Beginning in 2012 and 2015, King Saud University in Saudi Arabia and Sultan Qaboos University in Oman operated and maintained two nine-element, small-aperture arrays to enhance the scientific research capacity of low signal events. LLNL also started collaborations with the Saudi Geological Survey (SGS) on joint research projects to reduce earthquake risks and hazards. In 2014, US and Iraqi seismologists and engineers established the Mesopotamian Seismic Network, a permanent broadband network to further improve national earthquake monitoring capabilities. Data collected from the Middle East were used to determine earthquake source mechanisms and magnitudes, reduce uncertainties in earthquake locations, advance understanding of subsurface velocity and attenuation structures in the region, and provide new insights into mitigation and assessment of seismic hazards.

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# The prospects of establishing an NDC in The Gambia

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The recent experiences gained from the 2024 National Data Centre (NDC) training in Kenya and the NDC workshop in China have given us clear insights into the benefits of an NDC. Such benefits include a country's active participation in a world free from nuclear explosion, capacity building, access to International Monitoring System data and International Data Centre products, etc. The

Comprehensive Nuclear-Test-Ban Treaty Organization plays a pivotal role in the global nuclear disarmament and nonproliferation programme, with an emphasis on monitoring nuclear tests worldwide. Therefore, my study aims to highlight the significance of an NDC for The Gambia, which has signed and ratified the Comprehensive Nuclear-Test-Ban Treaty. The waveforms training provided me with valuable technical knowledge in signal analysis using Geotool for the first time, critical for monitoring nuclear tests, enhancing the country's capabilities in detecting nuclear explosions and obtaining other data related to environmental/ climate activities. Furthermore, the NDC meetings in The Gambia and China offered a deeper understanding of the strategic and operational roles of NDCs globally, showcasing the collaboration between States Signatories.

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## Precision Through Proximity: Enhancing Seismic Event Relocation with Local and Regional Networks

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Accurate seismic event location is essential for Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification. This study presents the relocation of a seismic event detected on 22 June 2024, using data from a temporary local network of 20 stations in Nakuru, Kenya, combined with approximately 8 regional stations. The event, initially reported at 2.2896° S, 39.1603° E by IRIS/USGS, varied significantly when analysed with different data sets: regional stations placed it at 0.289° N, 36.077° E, while the local network shifted it to -3.524° S, 37.894° E. The most refined location, using all available stations, was -2.121° S, 37.857° E. Data analysis was performed using Geotool and Seisan to achieve an integrated approach, reducing location uncertainty and enhancing depth estimates. This work demonstrates the critical role of combining local and regional data in improving event accuracy and verification capabilities, aligning with the goals of SnT2025 of fostering innovation, strengthening cooperation and building resilient scientific networks for global security.

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## Improvement to Use NDC in a Box SHI in Jordan, Enhancing SHI Processing and The Technical Expertise and Issues Learned

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The National Data Center (NDC) of Jordan has been in operation since 2014, and many developments have taken place in the NDC-JO until today. The Provisional Technical Secretariat updated NDC-JO components, provided technical assistance and training courses. Enabling us to effectively participate in the Comprehensive Nuclear-Test-Ban Treaty verification regime and improve the capabilities of the NDC, particularly in data analysis. Difficulties, challenges the NDC faced, and the technical issues and expertise learned led us to new visions for improving NIAB performance and International Data Centre (IDC) product distribution. These technical issues and expertise enable us to use International Monitoring System (IMS) data and IDC products in different fields. In my presentation, I will show the technical issues learned to improve SHI processing system, SOH and the analyst interface and suggestions for using other techniques like machine learning integrating for increasing accuracy and improving efficiency on waveform technologies, using data of IMS for reducing azimuth gap, determining correct location for local events and in performance monitoring and testing.

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**P5.2 Regional Empowerment** - Board: 13 / **P5.2-339**

## CTBT Technologies in the Verification Regime

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The International Monitoring System (IMS) uses four major technologies in its verification regime. The four technologies, namely seismic, hydroacoustic, infrasound and radionuclide are best suited to monitor the globe for any activities underground, underwater and in the atmosphere. The first three are the known waveform technologies that help to detect and locate events. Kenya, in collaboration with the Provisional Technical Secretariat, established two primary IMS stations (I32KE and PS24) and a well-equipped National Data Centre for data analysis. Our objective is to introduce data from other certified infrasound and seismic IMS stations over the last decade for scientific studies and civil applications using the PMCC, geo-tool etc. This presentation demonstrates how infrasound data is analysed and used to asses the impact of mining explosions and their effects on the environment. Additionally, we also focus on the seismoacoustic and regional events. Kenya is located within the seismically active rift system running all the way from Afar in the North to Mozambique, which is the main source of seismic activity in Africa. This study also aims to capture these events and their source implications and effects on the widening of the rift.

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## Benefits of the NDC in Costa Rica since 2012 and inter-institutional collaboration on the use of data from IMS monitoring technologies

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Since OVSICORI-UNA started using International Monitoring System (IMS) data, there has been significant progress in seismic data use, starting with the improvement of data acquisition systems like SeisComp and later incorporating infrasound and hydroacoustic data from IMS stations. Both the country and OVSICORI-UNA have benefited from various training programmes on the three IMS monitoring technologies. The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), in cooperation with the Government of Costa Rica, has also offered training in Costa Rica for users from Latin America and the Caribbean (LAC), improving data analysis skills. Users of the National Data Centre of Costa Rica have been trained in the different IMS monitoring technologies. Additionally, in 2010, a temporary infrasound station project was set up in Costa Rica with the support of the CTBTO. It is also important to involve more participants in the analysis and use of IMS data, such as SINAMOT, the Atmospheric Chemistry Laboratory and the UNA School of Physics.

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## Mainshock-Aftershocks Sequences in Distinguishing Anthropogenic and Natural Quakes: Case Study Turkana Rift, East Africa

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The volcanically and seismically active Main Ethiopian and East African (Kenya) rifts are linked in a complex zone within the Turkana Depression bounded by the Ethiopian plateau to the north and East African plateau to the south. Subsurface imaging beneath Lake Turkana and surrounding sub-parallel basins reveals multiple half-graben basins bounded by N-S striking normal faults. The objective of the study is to use the mainshock-aftershock sequence to distinguish anthropogenic and natural quakes. Data from 22 stations recorded on 3 May 2020, Mb4.9 event and its aftershocks. The data was processed using SEISAN software. The absolute locations of the events were improved using HypoDD double difference algorithm. Three maximum likelihood estimates (MLEs) parameter values (c, p and K0) describing Omori's law of decay rate were determined by AFTPOI program while four parameter values (c, p, K0 and $\alpha$) describing the statistical model MLEs were determined by ETAS program. A magnitude of completeness, Mc, of 1.62 and b-value = 1.33 ±0.24 for the sequence were determined. The ETAS model parameter values were c=0.0007, p=0.7071, K (0) =1.5361 and $\alpha$=1.217. The decay rate is not clear, as expected in quakes of this nature, due to the low population of events.

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# Enhancing Operational Excellence: A Comprehensive Training Strategy for IMS Station Operators

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The International Monitoring System (IMS) training programme for station operators, established in 1998, has been revised to meet evolving operational needs and ensure compliance with the draft IMS Operational Manual. This updated strategy addresses the diverse requirements of station managers, local operators, PKI operators and station operators, focusing on optimal performance and data availability. Key components include tailored training programmes based on needs assessment, blended learning methods (e-learning, in-person sessions, simulation based training and in situ sessions) and advanced technical training for equipment-specific troubleshooting. The foundation is a suite of interactive e-learning modules, ensuring standardized baseline knowledge. The strategy emphasizes quality assurance through key performance indicators, feedback and updates to maintain relevance and effectiveness. Modern methodologies like virtual reality, gamification and microlearning enhance flexibility and engagement. Training is categorized into basic, intermediate and advanced levels, with periodic refreshers. Collaboration with international trainers and manufacturers supports the broader Comprehensive Nuclear-Test-Ban Treaty verification regime, fostering a robust and proficient operational network capable of addressing IMS station challenges globally.

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# Training Cycle Approach for National Data Centres (TCAN2)

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The capacity building and training (CBT) programme supports States Parties' participation in the Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification regime by enhancing the technical capabilities of National Data Centres (NDCs). It provides tools, training and equipment to help NDCs receive, process and analyse International Monitoring System (IMS) data and effectively utilize International Data Centre (IDC) products. To maximize resources, the IDC implemented the Training Cycle Approach (TCAN1), which organizes interconnected training activities to strengthen NDC capacities in using IMS technologies while fostering collaboration among NDCs. TCAN1 focuses on improving NDC staff analytical skills through tailored tools and training. Building on this success, the upgraded TCAN2 incorporates lessons learned, introducing multilingual training and workshops, hydroacoustic training sessions and expanded online training opportunities. These enhancements address diverse needs and increase accessibility, further empowering NDCs to contribute effectively to the CTBT verification regime. This poster will showcase TCAN2's features and their impact on improving NDC technical skills, promoting international collaboration and strengthening global CTBT monitoring and verification efforts.

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## Contribution of Kazakhstan's Stations of the National Nuclear Center into Global and Regional Monitoring

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The monitoring network of the National Nuclear Centre (NNC) includes four seismic and one infrasound station, which are part of the International Monitoring System (IMS). In addition to these stations, the AFTAC arrays, the IRIS-NNC stations located on the territory of Kazakhstan, 11 three-component and two infrasound arrays of the NNC participate in global and regional monitoring as part of the NNC network. All data are collected and processed at the Kazakhstan National Data Centre. This report presents information on the contribution of Kazakhstani stations to REB by the number of associated phases in comparison with other IMS stations. Kazakhstan IMS stations are quite effective in monitoring and are among the best in terms of the number of associated phases among other IMS stations. This is confirmed by the maps of minimum magnitude epicenters and the ratio of the number of events by Kazakhstan stations to the total number in the Reviewed Event Bulletin (REB). At the regional level, the nature of events is discriminated and marked - earthquakes, industrial explosions, induced events. The real accuracy of determining the location of CA events in REB can be estimated by GT events. A collection of such events on the territory of Kazakhstan and an analysis of location accuracy are carried out.

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## Advanced Capacity Building System in Iraqi NDC and Event Data Analysis

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) has been instrumental in strengthening global monitoring networks through its International Monitoring System (IMS). This work specified the role of advanced capacity building system (CBS) installed at the Iraqi National Data Center (NDC) in May 2024, which enhances capabilities in data acquisition, analysis and event characterization by using a new version of software such as GeotoolQT and also inserts the IMS stations in SeisComP, which benefited us to detect more events about our region in real time. We put some events, for example, a seismic event in northern Iran on 5 October 2024, which was successfully detected using CBS. Additionally, the analysis of IMS data and International Data Centre products related to a major earthquake in Vanuatu, which occurred on 17 December 2024, at 01:47:23.760

UTC. This is a region with complex seismic and volcanic activity. The event was detected by three IMS technologies and includes data analysis with hydroacoustic stations with the integration of the location of the event with the seismic and infrasound data of the stations close to the event using the latest version of NDC in a box software complemented by non IMS stations data from Incorporated Research Institutions for Seismology (IRIS), such as stations of The Iraq Seismic Network.

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## Overcoming challenges of science outreach: Leveraging mobile technology for earthquake education in Latin America

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Traditional methods of science outreach, such as face to face courses and workshops, often face challenges such as limited resources and logistical obstacles. In Latin America and the Caribbean, where access to technology can be uneven, engaging the public with scientific knowledge requires innovative approaches. Recognizing the growing popularity and accessibility of mobile technology, especially among young people, the San Calixto Observatory has developed several digital strategies to promote earthquake safety awareness; with the support of Unifranz University, they launched 'Educientistas', an offline mobile application designed to educate students about earthquake preparedness.
Educientistas is a valuable tool to overcome barriers to science education and provides young people with essential knowledge to mitigate seismic risks. The next steps involve sharing knowledge regarding the ban on nuclear testing and the advantages of the International Monitoring System (IMS) data.

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## Participation of the Austrian and the Mongolian NDCs to the CTBTO Mentoring Programme

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In the framework of the Comprehensive Nuclear-Test-Ban Treaty Organization Mentoring Programme for early career women in science, technology, engineering and mathematics, experts from National Data Centers (NDC) served as mentors. The Austrian NDC, which is managed by a female seismologist, decided to take part in this initiative. The Provisional Technical Secretariat (PTS) selected an early career woman who is working as a seismologist for the Mongolian NDC as a mentee. We decided to focus on the evaluation of the National Preparedness Exercise (NPE) 2024 (NPE2024) – a verification exercise any interested NDC can take part in. The NPE was first proposed during the 28th session of Working Group B. The purpose of this exercise was to test the performance of the NDCs, as well as the data availability and quality of the PTS. NPEs are based on a fictitious scenario based on technologies provided by the IMS, as well as national data. The general task of participating NDCs was to assess the presence of potentially Comprehensive Nuclear-Test-Ban Treaty-relevant events using the information provided. In our view, this exercise proved to be an extremely valid mentoring approach, since it exposed the mentee to different data sets, technologies, processing software and products provided via the secure webpage. Overall, this hands-on experience enhanced the technical skills and confidence of the mentee.

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## Increasing the availability and safety by integrating CTBTO station and NDC Facilities as sensitive digital asset in the Framework of national cybersecurity programme

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Like several States Signatories, an auxiliary seismic station installation agreement was signed on 22 May 2001 between Senegal and Mr Wolfgang Hoffmann, Executive Secretary of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). It entered into force on 24 March 2006. In the same vein, Senegal, like all States Signatories, has access to the data of the International Data Centre (IDC) and even holds a National Data Centre offered by the CTBTO. These elements of the International Monitoring System and IDC networks are managed under the responsibility of the CTBTO, in whole or in part from the point of view of operation and availability and IT security. Often with on-site support staff for maintenance and operation, from the structure serving as a focal point. However, integrating this IT equipment and installations or operational technologies into the national register of sensitive digital assets to take them into account in a national IT security programme would allow for closer, more regular monitoring and consideration in the general budget of the structures in charge of digital technology and cybersecurity.

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# Empowering Venezuelan Seismological Service for Scientific and Civil Applications: Integrating IMS Technologies and Capacity-Building for Enhanced Regional Monitoring

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National Data Centres (NDCs) are crucial national technical organizations responsible for advising their authorities on verifying the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Standardizing processes and providing essential hardware, software resources, technologies and techniques for monitoring, acquisition, processing and data analysis are vital for optimizing the use and interpretation of data generated by the International Monitoring System (IMS). The capacity building programme empowers more countries to actively participate in nuclear test-ban verification through intensive technical training courses for experts. This programme equips NDCs with the necessary knowledge and tools for capacity strengthening while promoting international cooperation through meeting spaces and scientific-technical exchanges. Combined with the NDCs4All initiative, this enhances the effectiveness of the verification regime and aligns with global efforts to improve monitoring through scientific development and cooperation. This work presents the results of strengthening the NDC in Venezuela through the capacity building programme. It details how the acquired skills and tools from this programme, along with regional NDC cooperation, have optimized NDC Venezuela and empowered the Venezuelan Seismological Service for scientific and civil applications. This showcases the integration of IMS waveform technologies for monitoring regional seismic and tsunamigenic activity, and developing forensic seismology, thereby reinforcing local and regional capacities to address national and international needs.

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# A proposal to transfer Botswana National Data Center to a University environment

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There is an urgent need to transfer the Seismology Section (SMS) from the Botswana Geoscience Institute (BGI) in Lobatse to the Botswana International University of Science and Technology (BIUST) in Palapye. Once at BIUST, SMS can deliver infinite benefits like involving students to build capacity and develop future scientists specializing in the various technologies used in the Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification regime. As a Botswana National Data Center (NDC)

for CTBT, SMS conducts the CTBT implementation by handling Treaty-related activities on behalf of the Republic of Botswana to ensure that Botswana conforms to and fulfils her obligations under the CTBT. Botswana signed the CTBT on 16 September 2002 and ratified the Treaty on 28 October 2002. In the CTBT implementation, SMS deals with matters of global security and safety prohibiting all explosions of nuclear weapons with the ultimate goal of denuclearization towards a nuclear-weapons-free world. In contrast, the BGI as a national geological survey is mandated to improve the economy of Botswana by undertaking geoscientific mapping across the country and availing the data, information, updated maps and quality publications to help the mineral exploration and mining industries make discoveries of new economic mineral deposits.

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## Benefits of installation of Capacity Building System at NDC of Mexico

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The installation of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) capacity building system (CBS) at the National Data Center (NDC) of Mexico represents a groundbreaking step in advancing global seismological research and enhancing seismic risk mitigation. By harnessing the extensive data network provided by the International Monitoring System (IMS), this installation significantly improves the accuracy of earthquake detection and the assessment of their effects, such as ground motion and potential damage. The CBS empowers the NDC with cutting-edge tools and methodologies to analyse seismic data, enabling the development of impact models critical for disaster preparedness and mitigation. Furthermore, this initiative fosters international cooperation by strengthening technical capabilities of Mexico to contribute to global seismological research and practical applications. This strategic integration underscores the vital role of the CTBTO in reducing seismic risks, protecting communities and advancing the scientific understanding of earthquakes.

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## The Role of Technology and Analyst Expertise in Modern Nuclear Test Monitoring

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Over the past years, nuclear weapons test monitoring technologies have evolved enormously. This has made it possible to detect nuclear tests in all environments possible. The efficiency of the monitoring technologies and the capability of the analyst play a crucial role in nuclear weapon test monitoring. In this paper, we analyse an NDC Preparedness Exercises (NPE) and also present an overview of some of the most important developments in monitoring nuclear weapons and the associated challenges. We used geotool to analyse the seismic data for events that triggered the NPE2019 exercise. Both International Monitoring System (IMS) and Non-IMS stations were used to locate the event. From the analysis, the event occurred on 29 July 2019 at 23:17:49.9. at location, latitude, 48.0706 and longitude, 9.2222. The signature of the waveform obtained for the event clearly shows it was caused by an explosion as reported. We conclude that the ease with which events are located is augmented by the numerous IMS and non-IMS stations scattered around the world. However, the experience of the analyst and the capability of the software used for the analysis to accurately locate an event cannot be overlooked.

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## Infrasound Signals Detected of Auroral Electrojet Arcs in 2020 by Infrasound Stations along the Arctic Circle Region

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The natural phenomena, auroral electrojet arcs displays is observed periodically as the displays of bright lights in the sky in the polar latitudes regions, for both the Northern and Southern Hemispheres of the Earth. The auroral electrojet arcs display generate low frequency acoustic signals in the process which are sensitive to the sensors of the infrasound array network under favourable wind conditions for their propagation for detection. Three International Monitoring Systems infrasound stations (I18DK, I37NO and I3US) along the Arctic Circle region detected these infrasound signals from the auroral display in 2020. These infrasound signals were observed to be detected occasionally during certain periods of the year. Studying the propagation and detection parameters of these low frequency signals associated with the auroral, the frequency content of <0.1 Hz typically observed of this source with a pulsating infrasound signals with trace velocities <1 km/s. Preliminary studies showed a wide range of azimuths of detection for the source(s), indicative of a randomly moving source(s) in the atmosphere.

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# Seismoacoustic Analysis of 13 January 2025, Japan Earthquake

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A 6.6 magnitude earthquake occurred in the Hyuganada Sea off the coast of Kyushu, Japan on 13 January 2025. A 1 m high tsunami was associated with the event triggering the issuance of tsunami advisory by the Japanese government. The underwater eruptions of the Hyuganada Sea generate air waves and pressure waves that were used to study how the application of International Monitoring System (IMS) network data would assist in disaster mitigation. Analysis of the event was done using DTK-GPMCC. The parameters studied and analysed were phase, frequency, spectrum, magnitude, azimuth and slowness. These parameters were observed to be consistent with theoretic values. The results obtained from the seismic, infrasound and hydroacoustic stations were correlated to locate the event. The study concludes that the IMS network is operationally ready to contribute data towards a safer environment.

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# Study of Tectonic Plates Interactions Using IMS Stations: An Example of Inter-NDC Cooperation and Regional Empowerment

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Analyzing data and proper interpretation of the analyzed data are important for the operation of NDCs as they provide advice for both scientific and civil applications of these data. Having an analyst that can interpret data from the International Monitoring System (IMS) network is a challenge to some National Data Centres in the African region. To overcome this and enhance capacity building and regional empowerment, analysts from Nigeria, Tanzania and Kenya collaborated to analyse the earthquake that occurred in Xizange, Tibet on 7 January 2025. The study noted that the event was an intercontinental seismicity occasioned by tectonic plate interaction. The IMS network both at local, regional and teleseismic distances recorded the event. The analytical tool used to study event was DTK-GPMCC. The wave parameters of spectrum, fk, ray-tracing and azimuth for phase, magnitude, time and slowness were determined. This study therefore shows the importance of the Provisional Technical Secretatiat activities towards capacity development and regional cooperation.

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## Covering SnT2025 Conference for African Audience

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The Science and Technology (SnT2025) conference, organized by the CTBTO, provides a crucial platform for global discussions on advancements in monitoring and verifying compliance with the Comprehensive Nuclear-Test-Ban Treaty. For Ghana and the broader African continent, these developments hold significant implications for disaster preparedness, climate change and regional security. This paper outlines a comprehensive media strategy for covering SnT2025 for the EIB Network, particularly GHOneTV and StarrFM, to ensure that the key scientific insights and technological innovations discussed at the conference are accessible to Ghanaian audiences. Through interviews with leading scientists, in-depth analyses of thematic sessions and coverage of how these discussions influence global and regional policy-making, this report aims to bridge the gap between international science communities and Ghanaian viewers. Emphasizing the practical applications of these technologies for African countries, particularly in disaster risk reduction and climate resilience, the coverage will highlight the relevance of CTBT-related technologies in Ghana's socio-economic context.

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**P5.3 Outreach** - Board: 31 / **P5.3-004**

## Integrating public perception and science: understanding the global awareness of the CTBTO's mission

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The CTBTO plays a pivotal role in the prevention of nuclear weapons testing and the enhancement of global security. The fulfilment of its mission is contingent upon the continued development of its technological capabilities, as well as the maintenance of a positive public perception of its relevance and effectiveness. This study examines the manner in which public perceptions of science and technology interact with the role of the CTBTO, by examining the relationship between public awareness and trust in science and support for the CTBTO's objectives. Quantitative surveys on public attitudes towards S&T with qualitative interviews with stakeholders involved in disarmament policy were used. The results indicate that a significant proportion of respondents (aware of the CTBTO's mission) held a favourable view of its work. There was a positive correlation between trust in S&T and support for the CTBTO. Interviews with policy experts corroborate the hypothesis that the credibility and scientific rigour serve to reinforce CTBTO's capacity to garner international support for nuclear non-proliferation. An analysis of news-coverage indicates that regions with greater reporting on nuclear disarmament exhibit stronger public support for the CTBTO, whereas

those with less exposure demonstrate lower awareness, underscoring the necessity for more effective outreach strategies.

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## Low-cost seismometer for earthquake risk reduction in Nepal

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We established an initiative in Nepal to introduce seismology in schools, with a focus on education and citizen seismology. This program currently encompasses 33 secondary schools for: (1) the establishment of a network of affordable seismometer within the participating schools, and (2) the incorporation of earthquake-related education into the curriculum. We have prepared educational materials adapted to the Nepali school system, which we distributed and also share on our program's website: http://seismoschoolnp.org. While recording seismic events for education purposes, we have the opportunity to use those data in seismic source investigation. Our findings indicate that the overall outcomes are comparable, and all significant characteristics pertinent to seismicity are identified. We provide quantitative analyses regarding the locations, magnitudes and frequency distributions within our catalog. The variations between the two catalogs can largely be attributed to differences in network geometries, coverage and variations in daytime noise levels. We conclude low-cost seismic networks can serve as a viable and effective complement for monitoring seismic activity, as well as for educating students about seismic risk reduction.

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## Seismic hazard studies in Ghana and the success story

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Ghana is in a seismically active region and has experienced two major earthquakes of magnitude 6.5 on the Richter scale in 1862 and 1939. Twenty lives were lost in the two earthquakes and many structures were destroyed. In recent times earthquakes of magnitude 1.0 to 4.8 have been recorded in the country. This study is focused on the recent earthquake activities in Ghana and is intended to

raise awareness on the rising seismic activities and awaken relevant authorities and the public on the need for timely measures for mitigating the risks and disasters associated with earthquakes in Ghana. The National Data Centre in Ghana fourteen years on has made significant progress towards the goals of the CTBTO. The data Centre established in 2010 with the aim of monitoring compliance of the CTBT has also benefited the country in the monitoring of earthquakes. We are integrating IMS seismic data with our national data in the monitoring for our seismic hazard studies. This is one of the scientific benefits of the CTBTO to the NDC. The NDC is complementing the efforts of the Ghana Geological Survey Authority in monitoring seismic activity in the country with the data it receives from the IDC.

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## Keep CTBT Known to the Young and the Public

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While scientists and specialists have been persistently doing research and exploring every potential to push CTBT earlier ratification, people in other fields gradually turn their attention from this issue over time. It's therefore increasingly crucial now and in the future to educate younger generation, raise the public's awareness and keep the decision makers alert on the importance of CTBT for nuclear disarmament, international security and human well-being as well. First, there can be more courses and lectures on CTBT in universities and schools. Many issues are associated with nuclear test and nuclear weapons, such as climate change, public health, sustainable development, let alone the threats from nuclear accident, nuclear war and nuclear winter as well. Second, educators keep up with the updated progress of monitoring and verifying technologies and make good use of knowledge and scientific achievements on CTBTO website in class. Third, scientific and technical experts are supposed to engage more deeply and widely into the young students and the public. Fourth, the scientific and civil applications of any new verification techniques should involve more attention of the media, especially the New Media, through which to awaken the public and promote the concerned decision makers' early ratification of CTBT.

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**P5.3 Outreach** - Board: 35 / **P5.3-166**

## Women empowerment in nuclear diplomacy, nonproliferation and disarmament: Case study of the CTBTO Mentoring Programme

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The field of nuclear diplomacy, nonproliferation and disarmament currently faces significant challenges, including stagnation in advancing key agreements. The Comprehensive Nuclear-Test-Ban Treaty (CTBT), a cornerstone of the global nuclear order prohibiting all nuclear weapon tests, struggles to secure ratifications from Annex 2 States, delaying its entry into force. Integrating gender perspectives and prioritizing human resource development may provide innovative solutions to these challenges. Gender inclusion can diversify negotiations and foster creative approaches to nuclear arms control.
Recently, international organizations have launched educational, sponsorship and mentoring initiatives to enhance women's representation. Notably, the CTBTO Mentoring Programme supports early-career women in STEM, a critical field for advancing nuclear nonproliferation and disarmament discussions. By equipping female STEM professionals with the skills and opportunities to contribute, these initiatives aim to foster CTBT ratifications and broader nuclear diplomacy goals.
As part of a Master's thesis, this qualitative research will evaluate the CTBTO Mentoring Programme's impact on women's career advancement. Questionnaires will be distributed to mentees, and semi-structured interviews will be conducted with mentors and CTBTO representatives. This research will highlight the program's achievements, extract valuable lessons for other fields to contribute to scholarly discourse on women's empowerment in nuclear policy based on the sources availability.

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## The propagation of seismic waves, misinformation and disinformation from the 2024-10-05 M 4.5 Iran earthquake

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The 2024-10-05 Iran M 4.5 earthquake was a relatively unremarkable reverse-fault event, except that it took place at a time of heightened tensions in the Middle East. Its immediate aftermath saw widespread dissemination of misinformation, and potentially active disinformation, concluding that it was in fact a test of an Iranian nuclear weapon. The 'evidence' for many of these claims was based on inaccurate interpretation of seismic data. In this work, we analyse how geophysical 'fake news' propagated through social media (mainly Twitter/X) following this event, eventually gaining traction in mainstream, earned media. Although there were no significant geopolitical ramifications from the spread of this fake news, this event is nonetheless an illustrative warning of how seismic data can be misinterpreted and/or manipulated in public discourse.

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## Enhancing Public Awareness on the Role and Importance of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) and the RN52 Radionuclide Monitoring Station in the Philippines

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The CTBT, an international agreement aimed at prohibiting all nuclear explosions, was signed by the Philippines on 24 September 1996, and subsequently ratified on 23 February 2001. In alignment with its commitments under the CTBT framework, the Philippines operates the radionuclide monitoring station RN52, situated in Tanay, Rizal. Managed by the Philippine Nuclear Research Institute, it is designed to detect radioactive particulates in the atmosphere, which serve as indicators of potential nuclear detonation events. The Station has been integral to various civil and scientific endeavors, particularly in emergency preparedness and response. It has contributed to the assessment of the radiological impact following the Fukushima-Daiichi Nuclear Power Station incident in 2011 and has played a crucial role in the surveillance of nuclear tests conducted by other countries. Despite its significant operational history, public awareness regarding the CTBTO Station remains limited within the Philippines. Relevance of the RN52 Station is accentuated in light of recent developments in the nation's nuclear energy initiatives and the escalating risks associated with nuclear armament in the Asia-Pacific region. This presentation aims to elucidate various initiatives undertaken in recent years to promote the CTBT Station, alongside an analysis of feedback gathered from these outreach efforts.

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## Harnessing Virtual Technology to Empower Youth and Early Career Scientists for CTBT

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The integration of virtual technologies offers transformative potential for advancing the CTBT's objectives, particularly in building technical capacity among youth and early career scientists. By leveraging tools such as seismic and infrasound data analysis platforms, remote sensing simulations and interactive virtual labs, the CTBTO can provide accessible, scalable training in nuclear-test-ban verification. These tools deliver hands-on, immersive learning experiences that bridge theory with practical application, enhancing the operational efficiency of verification activities.

This study highlights how virtual tools empower youth and early career scientists, especially from developing regions, by ensuring equal access to high-quality training. Their scalability enables training large groups simultaneously, with reusable materials supporting continuous learning for future cohorts. This approach fosters a skilled, sustainable workforce prepared to uphold the CTBTO's verification mandate.
Innovative methods, such as virtual reality modules simulating on-site inspection (OSI) scenarios, collaborative platforms for real-time data analysis, and structured online learning, further enhance training impact. These strategies promote technical proficiency while fostering a diverse and inclusive community of experts.
By embracing virtual technologies, the CTBTO ensures the CTBT's sustained relevance, building resilience and continuity in its monitoring and verification regime for future generations.

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## Amplifying the CTBTO's Mission Through Art: Democratizing Science and Technology, Empowering Youth and Humanizing Nuclear Disarmament

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Art is free from limitations, welcomes challenges to the status quo, can make scientific and technical information more accessible and allows those whose voices are not heard in traditional political forums to participate in policy-making. It has the unique potential to change public perceptions and bring awareness to the CTBTO's mandate by democratizing scientific information and incorporating marginalized and youth voices to communicate data and research. Drawing from personal experiences as CTBTO Youth Group (CYG) member participants in the CYG's 2024 Global Art Campaign and the 2024 CYG Art Exhibition at the UN, this presentation explores how art amplifies the CTBTO's mission by inspiring public engagement, empowering youth and employing a form of visual and sensory storytelling that humanizes technical information.

Through this presentation, we aim to illustrate the role of art in promoting a global call for a nuclear test ban, which aligns with the CYG and CTBTO's mission and mandate. We will outline the unique ability of art to communicate scientific research and information, involving marginalized voices and youth, and propose further collaborative art initiatives building on the CYG's 2024 Global Art Campaign.

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## Science and Technology Conferences (SnT): History, Accomplishments and Role in Supporting CTBT

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This paper elaborates on the history, achievements and impact of the Science and Technology Conferences (SnT) in bolstering the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The paper tracks the evolution from the inaugural Synergies with Science Conference in 2006, the shift to the International Scientific Studies Conference in 2009 and the rebranding to SnT in 2011. These conferences have been instrumental in enhancing the CTBT's verification regime and fostering global scientific collaboration in areas relevant for the CTBT. Through the integration of advanced technologies and insights from leading experts, these gatherings have driven progress in nuclear test monitoring. While challenges persist, the conferences have contributed greatly to advancing the CTBT's objectives. This paper also suggests future directions to maintain innovation and collaborative efforts.

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## Teaching experience of the "Application of Earth Sciences in Nuclear Test Monitoring"

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After our participation in the 2014 CTBT Academic Forum, we decided to propose a formal course in the Earth Science undergraduate program offered in the Science Faculty at the National Autonomous University of Mexico (UNAM).
In August 2019, the elective course "Application of Earth Sciences in Nuclear Test Monitoring" was first taught for students enrolled in the bachelor's degree of Earth Sciences program at UNAM. The main objective of the course is to provide students with an overview of the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) as well as the use of the data generated for scientific and civil applications in Earth Sciences topics. A second objective is to inform students of the Mexican institutions about the CTBTO activities and working groups, and in the future be part of the different divisions IDC, IMS or OSI.
In this contribution, we present the syllabus being taught as well as students and teachers' reflections of the course. In addition, we present a future plan to promote the course not only between students enrolled in Earth Sciences but also on different bachelor's degrees being taught at UNAM.

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## Seizing the Moment: Leveraging Shifting Nuclear Attitudes to Strengthen the CTBT

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Global nuclear attitudes have significantly altered over the past five years. Renewed global power competition and destabilizing events have intensified public and policymaker focus on nuclear weapons. Amid this renewed relevance of nuclear weapons in global security discourses, the Comprehensive Nuclear-Test-Ban Treaty (CTBT) emerges as a critical stabilizing framework, offering an opportunity to reinforce international norms against nuclear testing. This abstract explores how global power competition and shifting perceptions of nuclear weapons have created a renewed urgency and opportunity for CTBT advocacy, with science diplomacy serving as a pivotal tool to advance these goals.

Drawing on data from surveys and qualitative studies, this presentation will analyze how public attitudes toward nuclear weapons have evolved since 2020. It will highlight the implications of these shifts for international cooperation and treaty universalization.

The presentation will further explore how science diplomacy can strengthen the CTBT's role in promoting stability through trust-building measures and supporting educational outreach to improve the "nuclear IQ" of policymakers and the public. By leveraging these approaches, the CTBT can serve not only as a tool for arms control but also as a platform for uniting diverse stakeholders around a shared commitment to preventing nuclear testing and ensuring global security.

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## Sustained Engagement of Early-Career Women in STEM: Evaluating Impact Through Key Performance Indicators (KPIs) in Indonesia's Commitment to CTBTO Initiatives

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) launched a pioneering mentoring program in 2022 to empower early-career women in science, technology, engineering and mathematics (STEM) from underrepresented regions, fostering gender equity and capacity building. Indonesia, a committed CTBTO member state, has played a significant role in this initiative by successfully mentoring seven participants over three program cycles. These mentees, hailing from institutions such as BRIN, BMKG, BAPETEN and Gadjah Mada University, have demonstrated measurable advancements in their technical expertise, leadership skills and contributions to international collaboration. This paper examines the program's impact using a Key Performance Indicator (KPI) framework to evaluate mentees' skill development, professional growth and broader contributions to Indonesia's active engagement in CTBTO initiatives. Metrics such as technical certifications, leadership responsibilities and participation in global scientific networks serve as indicators of success. The findings highlight the program's effectiveness while identifying areas for future enhancement. By leveraging KPIs, the study provides evidence-based recommendations to optimize mentoring programs, strengthen Indonesia's leadership in promoting gender equity in STEM, and

advance global cooperation in nuclear science. This approach underscores the potential for such initiatives to drive meaningful progress in capacity-building and diversity in STEM fields.

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## Will Annex 2 States Ever Ratify the CTBT? Tracing Policies, Analyzing Obstacles and Projecting the Future of Nuclear Test-Ban Diplomacy

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The Comprehensive Nuclear-Test-Ban Treaty (CTBT) remains a cornerstone of global nonproliferation efforts, yet its entry into force is stalled by the non-ratification of eight Annex 2 states. This paper explores the evolving policies of these states — specifically the United States, China, Egypt, Iran, Israel, India, Pakistan and North Korea — to identify key political, strategic and regional obstacles to ratification. It assesses how emerging trends, such as renewed arms races, great power competition and verification challenges, influence their decision-making. Special attention is given to how technological advances, including AI and satellite monitoring, can strengthen verification systems and build confidence in compliance. The analysis also addresses cyber threats to the International Monitoring System (IMS) and proposes enhancing cybersecurity as a crucial confidence-building measure. The paper argues that achieving CTBT ratification requires tailored strategies for each Annex 2 state, recognizing their unique security concerns and geopolitical interests. By examining historical trends and current dynamics, this paper projects future scenarios for CTBT diplomacy and provides actionable recommendations for breaking the diplomatic deadlock.

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## Integrating CTBT Objectives into ASEAN's Regional Framework: A Pathway to Universalisation

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Eroding trust among Annex II states and Russia's de-ratification of CTBT continue to hinder its entry into force (EIF). The stagnation in Annex II ratifications underscores the importance of universalising CTBT norms through regional cooperation. ASEAN presents a compelling case for such

an approach: while all ASEAN Member States have ratified the CTBT, the region remains susceptible, yet strategic, to major power dynamics. Renewed discourse on nuclear weapons further highlights the need to reinforce the relevant norms to avoid nuclear catasthrope. This research explores how ASEAN can advance CTBT universalisation through capacity-building initiatives that ensure the preservation of its norms, foster engagement with non-ratifying states and confidence-building measures. ASEAN's commitment to nuclear non-proliferation is reflected in its ongoing efforts to operationalise the Southeast Asia Nuclear-Weapon-Free Zone (SEANWFZ), which remains unratified by nuclear-weapon states (NWS), sharing similar challenge with CTCT. Additionally, leveraging ASEAN's expertise — such as the AHA Centre's role in disaster management — can strengthen technical cooperation, embedding CTBT norms beyond the political sphere. By integrating CTBT norms into ASEAN's broader security framework, ASEAN can reinforce the CTBT's inseparability from its non-proliferation and disarmament agenda while generating momentum toward CTBT EIF and eliminating motives for shifting away from its course.

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## From Devastation to Education: Leveraging Nuclear Tourism to Support the CTBT Entry into Force

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The Comprehensive Nuclear-Test-Ban Treaty (CTBT) represents a cornerstone in global efforts to eliminate nuclear weapons testing. However, achieving its universalization and entry into force remains a challenge. This presentation explores the concept of nuclear tourism as a transformative tool to raise public awareness about the catastrophic consequences of nuclear weapons testing. By organizing educational visits to historic nuclear test sites, such as the Semipalatinsk Test Site in Kazakhstan, related facilities, museums and nearby communities, nuclear tourism can vividly illustrate the long-term harm inflicted on human health and the environment. These immersive experiences, particularly impactful for younger generations, can foster a global movement against nuclear weapons testing. Amplified public awareness and opinion may exert pressure on policymakers to support the treaty's universalization, strengthen its norms and counter any resurgence of nuclear testing by nuclear-armed states. By turning sites of devastation into powerful educational platforms, nuclear tourism offers a unique avenue to advance the CTBT's mission and promote a nuclear-weapon-free future.

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## The Role of the National Nuclear and Radiological Security Support Center from Moldova in Non-Proliferation Education

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The National Nuclear Security Support Centre of the Technical University of Moldova celebrated its 10th anniversary in October 2014. Established by agreement of the Technical University of Moldova and the Moldovan Nuclear Regulatory Authority, the Centre has been active in educating the younger generation, including in nuclear security, non-proliferation and disarmament.
Over the years numerous presentations have been made at international conferences. Manuals and guides have been published on topics related to Centre's purposes, including roles of researchers in disarmament.
As part of its educational mission, the Centre has developed and included in the Curriculum for the second cycle of Master's studies, disciplines such as Nuclear Security and Cyber Risk and Research, Engineering and Culture of Non-Proliferation, which contain modules on the role of the CTBT in nuclear disarmament, by promoting confidence that any nuclear test will be detected. In addition, it is noteworthy the positivism of its mechanism for involving both NPT and non-NPT states in a constructive dialogue on the issue of disarmament.
The courses Curriculum are updated every two years, the most recent update including modules on non-proliferation, disarmament, cyber risks in critical infrastructures with nuclear activities and the ethics of research in the field.

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# Strengthening the CTBT Verification Regime through the Socialization of IMS Technologies: Insights from the Permanent Exhibition ¡Habla Tierra! Venezuela, Seismic Country

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The exhibition "¡Habla Tierra! Venezuela, País Sísmico" aims to enhance public awareness and understanding of seismic activities in Venezuela. This article presents the successful implementation of these initiatives and discusses the integration of International Monitoring System (IMS) technologies into the exhibition as a tool to complement the Capacity Building and Training program, highlighting the role of the National Data Centres (NDCs) in the Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification regime, pivotal in advising national authorities on treaty verification. The exhibition "¡Habla Tierra! Venezuela, País Sísmico" is part of a training program where young professionals are trained to multiply knowledge on seismic threat, while introducing the scientific environment where these skills are developed, aiming to encourage the formation of professionals in the geosciences field. This work presents an integrative proposal based on the formative process of the exhibition and its results, to connect, inspire and integrate diverse communities involved in nuclear-test-ban monitoring to enhance diversity across gender, geography and generations, and to include early career professionals and youth. It underscores the importance of international cooperation and capacity building in enhancing the verification regime and regional seismic monitoring capabilities.

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# Tangible Programming Learning for Visually Impaired Individuals

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Visually impaired individuals face challenges in both learning programming and engaging with exhibitions due to the predominantly visual nature of both activities. This project explores tangible block-based programming, where users interact with physical objects to construct computer programs. I am developing a web application that uses the TopCode JavaScript library, 3D-printed fossil models and audio feedback to create an interactive game. Users arrange physical model pieces to form a program, triggering audio prompts and storytelling that guide their exploration of the story. Initially designed for museum exhibitions, this approach can be easily adapted for CTBTO-related exhibitions, enabling visually impaired individuals to explore topics like on-site inspections, seismic monitoring and verification technologies through touch and sound. As tangible programming gains recognition for fostering inclusive STEM education, this project provides an accessible way to engage diverse audiences with CTBTO's mission.

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# Promoting the CTBT in a constantly changing media landscape

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The Comprehensive Nuclear-Test-Ban Treaty (CTBT) is a vital tool in the global non-proliferation and nuclear disarmament agenda, and in this regard the promotion of the CTBT is imperative. It is not only essential for the CTBT itself and nuclear disarmament issues, promoting the CTBT also contributes to the overall advancement of peace and security. But with the media landscape and the public information sphere constantly changing - not least the digital sphere and social media - it is increasingly challenging to reach different target groups and, more importantly, to have an impact with communications efforts promoting the CTBT. Add to those structural changes, such as Meta's recent announced changes to its content moderation policies, fact-checking and countering mis- and disinformation will be even more challenging. How can we better promote the CTBT and its entry into force and how can we achieve actual impact among stakeholders in this rapidly changing

media landscape? What are the challenges using digital communications tools and how can we contribute to countering mis- and disinformation? And how can we increase collaboration among international organizations on outreach efforts advancing the non-proliferation and disarmament agenda?

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## CTBT Non-Ratifying Non-Annex 2 States: What Are the Reasons for Delay? Examples of Nepal, Somalia and Yemen

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The Comprehensive Nuclear-Test-Ban Treaty (CTBT), established to prohibit all nuclear test explosions, stands as a pivotal framework in the global disarmament and non-proliferation regime. However, while the treaty has earned considerable support internationally, this three Signatory Non-Annex 2 States have yet to ratify it, raising questions about the underlying reasons for this delay. In this paper, the authors will explore the obstacles and difficulties that stand in the way of the three Non-Annex 2 States, which have not been able to ratify the CTBT. These countries are often characterized as facing a complex interplay of political instability, financial issues and security concerns, with domestic priorities often overshadowing international commitments. For example, in Somalia and Yemen, ongoing conflicts exacerbate the challenges associated with the treaty ratification, diverting governmental focus and resources. In turn, Nepal's socio-political landscape presents its own set of challenges that complicate and delay the ratification process. This paper aims to explore the multifaceted factors that block progress toward CTBT ratification among these states, illuminating the broader implications for internal and external constraints. By addressing and tackling these challenges, the Preparatory Commission for CTBTO could facilitate both the entry into force of the treaty and its subsequent successful implementation.

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**Panel "Global Innovations: Waveform Technologies"** - Board: 0 / **Pa01**

## Global Innovations Part I: Waveform Technologies

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Technology refreshment is an important part of CTBTO's mission. The IMS was designed in the 1990s, often using equipment and technology that was mature at that time. As technology advances,

the possibility arises that sensing technologies that were not available at the beginning of the IMS may be capable of improving its performance, robustness and sustainability. The panel will discuss technological developments relevant to the fields of seismology, hydroacoustics and infrasound sensors that may help shape the future of CTBTO's monitoring network.

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**Panel "Global Innovations: Radionuclide Technologies"** - Board: 0 / **Pa02**

## Global Innovations Part II: Radionuclide Technologies

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Innovation is playing an important role today and will even play a more critical role in the years to come. This also applies to the RN technology / equipment currently in use in the IMS network and OSI. The panel will discuss topics such as: the impact of cutting-edge technologies and novel materials in radionuclide detectors design and sensitivity, including AI and ML; understanding whether the RN monitoring system has reached the desired level of maturity; the use of remotely controlled platforms in the field of radionuclide detection; the use of radionuclide data fusion tools; and next steps in the development of radionuclide detection technologies.

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**Panel "Operational Detection Capabilities of the CTBTO"** - Board: 0 / **Pa03**

## Operational detection capabilities of the CTBTO

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This panel will discuss the real, current detection capability of the IMS, addressing all technologies, individually as well as the fusion between them, and the impact on AI on improving the detection capabilities. The panel will discuss the evolution of IMS detection capabilities with time, the level of development of IMS technologies and processing algorithms, and the benefits of considering monitoring technologies in an integrated way.

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**Panel "The Impact of Extreme Conditions on the CTBT Monitoring System"** - Board: 0 / **Pa04**

## The impact of extreme conditions on the CTBT monitoring

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This panel will broaden the understanding of extreme environment effects on the CTBT's operations and the potential for CTBTO to contribute to environmental resilience through data sharing and adaptive practices. The panel aims at sparking discussion on how CTBTO's data can be leveraged to enhance the understanding about our planet and support global risk mitigation. By bringing together experts and engaging the audience in a forward-looking dialogue, the panel will highlight the CTBTO's role and needs in today's world.

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**Panel "Machine Learning, Deep Learning and High-Performance Computing: Transforming CTBTO's Operations in Global Monitoring and Verification"** - Board: 0 / **Pa05**

## Machine Learning, Deep Learning, and High-Performance Computing: Transforming CTBTO's Operations in Global Monitoring and Verification

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How can emerging technologies (e.g. machine learning, deep learning, artificial intelligence, cloud computing, etc.) support our core business / mission / verification sciences? The session will draw the connection between CTBTO tasks (data verification related activities) and ML/DL opportunities, identify infrastructure support for ML/DL-related activities, and discuss how to integrate ML/DL techniques into CTBTO-related software.

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**Panel "Gender, Geography, Generations: How NDCs Shape the World Today and Tomorrow"** - Board: 0 / **Pa06**

## Geography, Gender, Generations: How NDCs Shape the World Today and Tomorrow?

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This panel will focus on strengthening the National Data Centre (NDC) community through sharing experience and collaboration at multiple levels: at the national level, it will highlight internal coordination among institutions, showcase successful national collaborations, and share best practices and lessons learned within individual NDCs; at a regional level, the panel will explore mechanisms for knowledge transfer and collaboration among NDCs, emphasizing peer learning and mutual support within and across regions; and at a global level, the panel will mention strategies to inspire and support emerging NDCs worldwide. It will also feature the NDCs4All initiative, illustrating how global partnerships and inclusive approaches can accelerate progress and help NDCs collectively contribute to broader CTBTO goals.

**E-mail**:

**In-person or online preference**:

**Panel "IMS sustainment now and into the future"** - Board: 0 / **Pa07**

## IMS sustainment now and into the future

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Panel on the technological and logistical challenges of ensuring the long-term sustainability of the IMS network into the future. The outcomes of the panel will be to learn from the various strategies and discussions proposed in order to constantly improve the IMS sustainment strategy, and this will be obtained through: encouraging network managers/operators to share their experiences and plans/strategies when it comes to network sustainment; identifying lessons that could enhance the development of the IMS sustainment strategy; and exploring areas of collaboration.

**E-mail**:

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**Panel "The Treaty Verification Regime across the Generations"** - Board: 0 / **Pa08**

## The Treaty Verification Regime across the Generations

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The IMS network was designed in the 1990s, and in the future there might be room for further improvement or optimization considering recent technologies and lessons learned from the many years of operation. The roundtable will be preceded by a keynote presentation about the history of the Group of Scientific Experts' (GSE) work, the Treaty negotiations and the technical rationale for the Verification Regime as we know it today.

**E-mail**:

**In-person or online preference**:

**Panel "Utilizing Data from On-Site Inspection Activities: Insights from OSI Exercises and Field Tests"** - Board: 0 / **Pa09**

## Utilizing Data from On-Site Inspection activities: Insights from OSI Exercises and Field Tests

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This panel will provide a forum for engaging a wider community to contribute to the OSI techniques development via utilizing data from OSI Exercises and Field Tests for the development and testing of new, innovative approaches. It will add emphasis on engaging early-career experts and experts from the under-represented geographical regions. While OSI Exercises are focused on the assessment of the current OSI capabilities for the full range of OSI techniques, OSI Field Tests provide a means to

also test the suitability of emerging technologies and approaches for the OSI use, as well as potential opportunities to engage with a wider community that may share OSI-relevant interests.

**E-mail**:

**In-person or online preference**:

**Panel "Bridging Worlds: Future Leadership for a Safer World"** - Board: 0 / **Pa10**

## Today's Minds Tomorrow's Innovators - Bridging Worlds: Future Leadership for a Safer World

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) is uniquely positioned at the intersection of science and diplomacy. To sustain the talent needed to achieve a world without nuclear tests, the CTBTO continues to invest in cultivating the next generation of leaders in STEM, and nuclear disarmament and non-proliferation, from across the world.

This panel will bring together some of Today's leaders in science and diplomacy with Tomorrow's innovators to explore how multiple perspectives and forward-thinking leadership across these two critical fields is essential for building a safer world.

Through intergenerational dialogue between seasoned and emerging professionals, the session will also examine the challenges faced by leaders within diplomatic and technical fields and spotlight initiatives undertaken to address them, such as the CTBTO Mentoring Programme for early-career women in STEM and the CTBTO Research Fellowship, which empower, inspire and prepare young professionals to thrive. It will further showcase why mentorship, research fellowship, and policy engagement are effective tools to create leadership pathways in both technical and diplomatic careers, amplifying the contributions and voices of those promoting peace, security, and scientific advancement.

By bringing everyone together, we expand our collective ability to innovate, mediate, and lead. This session offers a platform for transformative dialogue, reflection, and inspiration. Together, we can reshape the landscape of science diplomacy to ensure that the future is nuclear-test free.

**E-mail**:

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**Panel "Adapt or Become Obsolete: Emerging Technologies as a Means to Achieve International Organizations' Mandates and Goals"** - Board: 0 / **Pa11**

## Adapt or Become Obsolete: Emerging Technologies as a Means to Achieve International Organizations' Mandates and Goals

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As technology evolves at an increasingly rapid pace, international organizations (IOs) are innovating and using new tools and methodologies to achieve their goals. From verification and monitoring mechanisms to disaster risk reduction and environmental protection, emerging technologies are transforming the ways IOs operate and address global challenges. This panel will explore how organizations can and are using cutting-edge technologies to enhance their effectiveness and efficiency.

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**PTS session** - Board: 0 / **PTS-549**

## Senior Management engagement in OSIs

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The Provisional Technical Secretariat (PTS) of the Comprehensive Nuclear Test Ban Treaty Organization's (CTBTO) has been actively working on the build-up of the On-Site Inspection (OSI) element of its verification regime over the course of the last years. One of the essential tools in these efforts is the conduct of exercises as a valuable opportunity to test, validate and further enhance the inspection techniques, activities, processes and procedures enabled by the Treaty.

Under the framework of the OSI Exercise Programme for 2022-2025 a series of tabletop exercises were organized in 2022 and 2023 to foster the engagement of the PTS senior management as well as to enhance their understanding of OSI policies and processes and to prepare them for their roles and responsibilities in the Build-Up Exercise (BUE24) and the Integrated Field Exercise (IFE).

This poster intends to provide a brief presentation of these exercises, including their proceedings, main outcomes and lessons learned. It also strives to showcase the continuous efforts of the PTS in achieving the organization's readiness for OSI once the Treaty enters into force.

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**PTS session** - Board: 0 / **PTS-805**

## The development of a long term strategy for the sustainment of the International Monitoring System Sustainment

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Sustaining the International Monitoring System (IMS) network, operated by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), has become one of the key focus areas of the CTBTO as the installation and certification of more than 90% of the IMS network facilities is complete. The network has evolved over time from the initial focus on station installation and certification, to maintenance of stations, to the current situation where the primary focus is on sustainment. A significant proportion of IMS stations will exceed 20+ years of continuous operation. It is therefore expected that an increasing number of stations and their infrastructure will need to be recapitalized. In anticipation of this, a sustainment strategy for the IMS has been developed that includes a comprehensive understanding of the lifespans of the subsystems at IMS stations for all technologies, the ages of the currently installed subsystems, and the anticipated time when certain stations will

require recapitalization. This strategy has enabled the CTBTO to develop various scenarios and their associated risks that can be considered over the next 20 years.

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**PTS session** - Board: 0 / **PTS-875**

## Enhancing the Role of National Data Centres in CTBT Verification: A Framework for Capacity Building

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National Data Centres (NDCs) are pivotal to the Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification regime, enabling States Parties to independently analyze data from the International Monitoring System (IMS). Beyond treaty verification, NDCs contribute to national security, scientific research, and disaster management. The abstract outlines a comprehensive framework for establishing and operating an NDC, emphasizing capacity building through two pillars: individual competence and organizational capability. Individual competence focuses on knowledge, skills, and abilities development through foundational education, technical training, and workforce planning. Organizational capability encompasses infrastructure, data management systems, and collaboration mechanisms to ensure operational efficiency. Key roles of NDCs include secure data handling, independent IMS data analysis, event screening, and advisory support to national authorities. Tools and processes are highlighted for effective event classification, reporting, and integration with the broader verification regime. The abstract also underscores the importance of capacity-building resources provided by the International Data Centre (IDC), regional collaboration, and knowledge networks to enhance technical proficiency and operational sustainability.
A practical self-assessment checklist is introduced to guide NDCs in evaluating their effectiveness and aligning with CTBT obligations, fostering a robust verification network and contributing to global security and scientific advancements.

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**PTS session** - Board: 0 / **PTS-881**

## IDC Software for NDCs, Status and Future

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To address the mandate as given under the CTBT Protocol (part I, paragraph 22), to provide technical assistance to States, the International Data Centre (IDC) is responsible for a dynamic Capacity Building and Training Programme. The provision of software is a fundamental part of the assistance, as it provides the States; through their National Data Centres – NDCs; with resources to enable them to use the IMS Data and the IDC Products for treaty verification related issues (as well as for issues of national interest, by incorporating IMS data and/or IDC information with local resources). The NDC-in-a-Box (NIAB) is a collection of computer programs (software suite) that can replicate the results of the IDC and offer the opportunity to apply user criteria to process IMS Data. This presentation gives a portrait of the status of the NIAB and discusses the past and present strategy for its development, also in the foreseeable future.

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**Side event on metrology** - Board: 0 / **SE01**

## The Role of Metrology in Seismic, Hydroacoustic, and Infrasound (SHI) Monitoring Activities

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This event will explore recent advances in metrology for SHI technologies and their application within the CTBTO verification regime. It will focus on the transfer of laboratory calibration methods to the field, address key technical challenges, and highlight the importance of strengthening calibration traceability to ensure reliable IMS data.

Session Objectives:
- Review the most recent developments in metrology related to IMS seismic, hydroacoustic, and infrasound (SHI) monitoring, representing the state-of-the-art.
- Consider how laboratory calibration capability can be transferred to the field calibration requirements of the IMS.
- Outline the technical challenges and highlight further research necessary to fully implement field calibration requirements and establish measurement traceability for IMS seismic, hydroacoustic and infrasound data.
- Encourage manufacturers of SHI equipment and operators of SHI systems outside the IMS to contribute to the developments in metrology related to instrumentation and adopt a unified approach to calibration techniques compatible with IMS methods and requirements.

This side event provides an opportunity to share experiences and successes from across technologies and from geophysical monitoring activities beyond the IMS.

**E-mail**:

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**Side event on Artificial Intelligence (AI)** - Board: 0 / **SE02.02**

## AI at International Organizations: Opportunities and Challenges

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Artificial intelligence (AI) methods have had recently significant impacts in science and technology, on redefining operations and overall, on innovation and efficiency. These methods for generating models from datasets or logic-based algorithms that emulate aspects of human performance can similarly accelerate all aspects of the work of CTBTO and other international organizations. For CTBTO, AI presents a unique opportunity to enhance monitoring, data analysis, development, operations, decision-making processes and more. This event aims to explore the current state of the art, outlines challenges and identifies priorities for future AI activities in the fields of science and technology and beyond for the CTBTO and other international organizations.

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**Side event on Artificial Intelligence (AI)** - Board: 0 / **SE02.03**

## AI in the Industry: Driving Innovation, Efficiency & Growth

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**Overview**
Artificial intelligence (AI) is no longer a futuristic concept; it's a transformative force reshaping every aspect of the industrial landscape. From station operations to global workflows, AI is moving beyond simple automation to create intelligent, predictive, and collaborative systems. This event provides a deep dive into the practical applications and strategic implications of AI for organizations today.
**Synopsis & Concept**
This session is designed for managers, supervisors, engineers, IT professionals, and innovators seeking to understand how AI can be leveraged to solve real-world operational challenges. Participants will explore the latest trends, proven use cases, and tangible benefits such as increased efficiency, reduced costs, and enhanced safety.
Structured around key themes, the session features a combination of keynote speeches, panel discussions, and interactive discussions. Attendees will gain a comprehensive understanding of adopting and scaling AI within their organizations, while addressing critical ethical and regulatory considerations associated with this powerful emerging technology.

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**Side event on YPN / SE03**

## Young Professionals Network (YPN): Building the next generation of specialists to carry the CTBT mission

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The Comprehensive Nuclear-Test-Ban Treaty (CTBT) relies on a global network of experts in science, technology, policy, and operations. Building the next generation of specialists to carry this mission forward is central to the work of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO).
This panel offers insights into career pathways within the CTBTO and the wider field of nuclear explosion monitoring. Panellists will share their personal career journeys, highlighting the skills,

experiences, and opportunities that shaped their professional development. They will also discuss the many entry points into this field, from scientific research and technical innovation to international collaboration and capacity-building.
The session provides practical perspectives on building a career in this highly interdisciplinary area. Following presentations, a moderated discussion will address common challenges and opportunities in pursuing careers linked to the CTBTO's mandate.
The event will conclude with an open Q&A, giving participants the chance to engage directly with the panellists and seek advice on their own professional aspirations. Join us to explore how you can contribute to global non-proliferation and disarmament efforts.

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**Side event on DAS** - Board: 0 / **SE04**

## The Present and Future Role of DAS for NDC and Implications for the CTBTO

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The Danish NDC and the Danish Embassy are organizing a panel debate on fiber sensing at the upcoming SnT2025. Fiber sensing is in the process of transforming how we detect signals from explosions and earthquakes. National seismic networks around the globe are working on methodologies for including Distributed Acoustic Sensing (DAS) in their daily work, a technology that also has enormous potential for hydroacoustic sensing using existing submarine fiber cables. This event will kickstart a discussion on new monitoring technologies for seismology (and hydroacoustic?). What are the advantages? What are the limitations of fiber sensing? Should IMS / OSI include fiber sensing, and would this be possible within the current wording of the treaty? What would be the challenges for NDCs in terms of downloading and integrating IMS DAS-data? And the challenges for OSI? The participants in this panel will be representatives from NDCs, PTS, DAS experts and cover a deep understanding of the technical possibilities within the treaty.

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**Working at the CTBTO - Recruitment Session** / **SE05**

## Working at the CTBTO - Recruitment Session

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Join us for an exclusive HR connect event – your gateway to exciting employment opportunities, recruitment process insights and tips for a standout application.

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**Working at the CTBTO - Recruitment Session / SE06**

# Working at the CTBTO - Recruitment Session

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