Infrasound Technology Workshop 2016 (ITW2016)

Report of Contributions

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ID: Type: **Oral**

Infrasound technology developments

The IDC advances its methods and continuously improves its automatic system for the infrasound technology. The IDC focuses on enhancing the automatic system for the identification of valid signals and the optimization of the network detection threshold by identifying ways to refine signal characterization methodology and association criteria. An objective of this study is to reduce the number of associated infrasound arrivals that are rejected from the automatic bulletins when generating the reviewed event bulletins. A number of ongoing projects at the IDC will be presented, such as: - improving the detection accuracy at the station processing stage by replacing the infrasound signal detector DFX-PMCC (Detection and Feature eXtraction – Progressive Multi-Channel Correlation) and by evaluating the performances of detection software; - development of the new generation of automatic waveform network processing software NET-VISA to pursue a lower ratio of false alarms over GA (Global Association) and a path for revisiting the historical IRED. The IDC identified a number of areas for improvement of its infrasound system, those will be shortly introduced.

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Presenter: MIALLE, Pierrick (CTBTO Preparatory Commission)

Track Classification: 1. IMS, IDC and NDC Infrasound Projects

ID: Type: **Oral**

# of IMS infrasound station and engineering projects

The infrasound component of the International Monitoring System (IMS) is composed of sixty stations. Forty-nine of them are already certified and transmit data in near real-time to the International Data Centre, Vienna, Austria. Each infrasound station is composed of an array of infrasound measurement systems capable of measuring micropressure changes produced at ground by infrasonic wave propagation. The Provisional Technical Secretariat (PTS) of the Comprehensive Nuclear-Test-Ban Treaty (CTBTO) is working towards the completion and operation of the IMS infrasound network. The objective of this presentation is to review the main IMS infrasound station and engineering projects conducted over the last year. This includes station construction, certification, major upgrade and revalidation activities as well as projects to improve station reliability and resilience and increase compliance with IMS Operational Manual requirements.

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Track Classification: 1. IMS, IDC and NDC Infrasound Projects

ID: Type: **Oral**

-house infrasound instrumentation: customized, convenient, lower cost

Researchers can benefit from designing and building custom instruments, achieving greater convenience at a lower price. As an example, we present an infrasound logger (named the Gem) designed specifically for campaigns on volcanoes. Unlike commercial alternatives, the Gem is inexpensive, specialized for volcano fieldwork, and user-serviceable. It has a fraction of the per-channel cost of other infrasound systems, and being a single-channel instrument means that sensor cables (which are heavy, bulky, and tangle-prone) are unnecessary. These priorities, along with its small size and light weight, make it suitable in large-N campaigns and in sites with risks to instruments or difficult access. Projects outside of volcano infrasound, including along rivers and in the stratosphere, have also found the Gem useful due to these characteristics. In-house instrument design may be beneficial for other labs as well. Several companies now offer user-friendly electronic components, and open-source software is available for designing circuits and programming firmware. These developments make instrument design accessible to non-engineers in many cases. Custom instrumentation can be especially helpful in small fields (like volcano infrasound) where commercial instruments can be expensive and inconvenient. Therefore, we expect to see the emergence of more custom instruments in the coming years.

Primary author: ANDERSON, Jacob Fortner (Boise State University)

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Track Classification: 2. Instrumentation

ID: Type: **Oral**

in On-Site Station-Performance Measurement and Diagnostics

An acoustic-impedance probe has been developed for the purpose of on-site evaluation of pipe-based wind-noise-reduction systems (WNRS) and microbarometers. The probe generates a controlled volume displacement using a precision graphite-in-glass piston. The displacement is measured with a linear variable-displacement transformer (LVDT) and the acoustic pressure is measured with a DC-coupled pressure transducer. The magnitude and phase of the acoustic impedance is calculated from the measured volume displacement and pressure. If an arm of a WNRS is disconnected from the microbarometer and the probe attached to the WNRS, the impedance can be measured. Even a single inlet-blockage in a 24-pipe rosette arm can be detected by the change in impedance. In addition to measurement of acoustic impedance, the probe can be used to drive the microbarometer directly thereby performing a field calibration of that microbarometer. Both modes of operation were demonstrated at the Sandia National Laboratory Facility for Acceptance, Calibration, and Testing (FACT). In this demonstration, the probe was used with two varieties of WNRS with artificially introduced faults. The probe was also used to measure the magnitude and phase of the frequency response from 0.03 to 0.5 Hz of a microbarometer in the field.
[Funded by the US Department of State, Contribution in Kind]

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Track Classification: 2. Instrumentation

ID: Type: **Oral**

Event Detection via Free Flying Stations in the Stratosphere

Infrasound stations on free floating balloons suffer little wind noise, are entirely decoupled from ground vibrations, and have a greatly extended detection range compared to those on the ground. Despite the potential advantages of such stations, few studies have addressed the research and operational opportunities afforded by free flying sensors. The last three years have seen several infrasound deployments in the free atmosphere, however, allowing in depth analysis of operational potential. Three flights were multi-hour deployments over the American southwest, one flight was a long duration circumnavigation of Antarctica, and another was an attempt to record known ground sources from the stratosphere above central New Mexico, USA. Noise levels will be compared with those of nearby ground sensors, and the general infrasound event detection capability of stratospheric stations will be assessed. Disadvantages such as variable station location, low amplitude response, and susceptibility to electromagnetic interference will be addressed as well.

Primary author: BOWMAN, Daniel (Sandia National Laboratories)

Presenter: BOWMAN, Daniel (Sandia National Laboratories)

Track Classification: 2. Instrumentation

ID: Type: **Oral**

Infrasound Sensor Self-Noise

Sensor self-noise may be defined as the output signal from the sensor in the absence of an external stimulation. Typically this is measured using sealed instrument ports, and ideally in a chamber with significant environmental isolation. Such a measurement is referred to as a "static self-noise measurement." It is also possible to apply a known signal to the sensor being tested, and obtain an estimate of the resulting "dynamic self-noise". Dynamic self-noise measurements include non-linear effects, and the noise-floors obtained this way can provide a more realistic estimate of the actual measurement noise-floor in the presence of signals. Various algorithms for estimating dynamic self-noise will be considered here, as well as methods for improving the estimates for static self-noise. The effect of signal-to-noise and signal amplitude on the dynamic self-noise estimate will be considered. The utility of the Hyperion Model 5000 series sensor, which provides both seismic and pressure channels, for evaluating sensor-self noise methodologies will be discussed.

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Track Classification: 2. Instrumentation

ID: Type: **Oral**

Evaluation Capabilities at the Facility for Acceptance, Calibration, and Testing (FACT)

Researchers at the Sandia National Laboratories Facility for Acceptance, Calibration, and Testing (FACT) site have been working to expand capabilities for the evaluation of infrasound sensors. These capabilities include an improved infrasound isolation testing chamber and expanded field sites with an installed infrasound array. The new infrasound chamber improves upon the isolation of the sensors under test from ambient pressure and temperature conditions, allow for a greater volume for testing more sensors simultaneously, support pressurization and evacuation to simulate different altitudes, and include a driver for generating higher pressure signals than had previously been achievable. The infrasound field stations at the FACT Site Array cover an aperture of up to 3 kilometers and allow for the simultaneous deployment of multiple sensors and wind filter designs at each element for easy comparison over a long-term deployment.

Primary author: MERCHANT, Bion John (Sandia National Laboratories)

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Track Classification: 2. Instrumentation

ID: Type: **Oral**

Results from the US NACT R&D Testbed Infrasound Array

Previously, no US-based facility existed for year-round testing and evaluation of infrasound equipment and designs in the field. The US Nuclear Arms Control Technology (NACT) R&D Testbed at the Sandia National Laboratories (SNL) FACT site has therefore been designed so infrasound equipment and designs can be tested in a realistic environment before they are deployed at IMS stations. In March 2016 the University of Alaska Fairbanks and SNL installed a 4-element infrasound array at FACT. Two of these elements serve as "focus elements" with multiple wind noise reduction systems (WNRS): a rosette pipe array and polyethylene hose system. At these elements, a single digitizer powers two Chaparral 50A sensors (connected to a separate WNRS), two reference sensors, and a meteorological system. A related project installed a 6 m wind noise reducing dome at one of the focus elements. The other two elements have only the polyethylene hose system deployed. Seismic elements will be installed in late 2016. Here we present preliminary results from the FACT site infrasound array. In situ frequency response techniques are used to evaluate the frequency response of the different noise reduction techniques and sensor performance. Noise reduction is also compared between the different systems.

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Track Classification: 2. Instrumentation

ID: Type: **Oral**

NDC Project: Acoustic Surveillance of Hazardous Volcanic Eruptions (ASHE) in Asia

The ASHE Ecuador (2004-2012) collaboration between Ecuador, Canada, and the US demonstrated the capability to use real-time infrasound to provide low-latency volcanic eruption notifications to the Volcano Ash Advisory Center (VAAC) in Washington DC. The Atmospheric dynamics Research Infrastructure in Europe (ARISE, 2012-2018) supported by the European Commission fosters integrating innovative methods for remote detection and characterization of distant eruptive sources through collaborations with the VAAC Toulouse and the Comprehensive Nuclear-Test-Ban-Treaty Organization (CTBTO). The ASHE Asia project proposes an international collaboration between the Earth Observatory of Singapore, the VAAC Darwin, National Data Centers in Japan and Palau, and will receive the support of ARISE, to provide improved early notification of potentially hazardous eruptions in Asia and the Western Pacific using a combination of established technologies and next-generation mobile sensing systems. The increased availability of open seismoacoustic data in the ASEAN region as well as recent advances in mobile distributed sensors networks will facilitate unprecedented rapid progress in monitoring remote regions for early detection of hazardous volcanic eruptions and other natural disasters.

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Track Classification: 3. Data Processing and Station Performance

ID: Type: **Oral**

# of Tengchong infrasound array in China

The Tengchong seismo-acoustic array located in southwest of China has been running for 5 years. We perform broadband (0.01–5 Hz) array processing with the infrasound continuous waveform data (from 1 January 2011 to 31 December 2015) using the Progressive Multi-Channel Correlation algorithm in 15 log-spaced frequency bands defined by Matoza et al.(2013).The detection results show microbaroms [0.1-0.5 Hz] come from azimuth between 180 and 240◦ during April to October related to the significant wave height in southern India ocean,but microbaroms come from azimuth between 30 and 90◦ during September to March related to the significant wave height in northern Pacific ocean. MAWs [0.01-0.1 Hz] come from azimuth between 270 and 360◦ and between 90 and 160◦ . The detections with azimuth between 100 and 150◦ in December 2014 to January 2015 may be related to the several typhoons from the Western Pacific ocean. The PMCC results confirm that the coherent signals typically exhibit systematic seasonal variations.

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Track Classification: 3. Data Processing and Station Performance

ID: Type: **Oral**

infrasound signal durations provide constraints for network signal association algorithms?

Signal association across the International Monitoring System (IMS) infrasound network is challenging. Several factors contribute to the difficulty in identifying events that generate multiple observed infrasound signals across the IMS including: the sparseness of the network, the variability in signal propagation speed (celerity), and the lack of signal characteristics that contain information about source-to-receiver range. One signal characteristic that has not been subject to extensive investigation is signal duration. Here we test the hypothesis that signal duration contains information about source-to-receiver range, despite the expected complications due to propagation variability. We present a methodology for objectively measuring signal duration, which is applied to a suite of over 40 ground truth signals recorded on IMS infrasound arrays during the past 15 years. Preliminary results suggest that signal duration has a weak relationship with source-to-receiver range. Nevertheless, this allows bounds to be placed on the likelihood of a short duration signal being associated with an event at a large distance away from the array. The effects of signal-to-noise ratio will also be discussed.

Primary author: GREEN, David (AWE Blacknest)

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Track Classification: 3. Data Processing and Station Performance

ID: Type: **Oral**

Heave Cancellation for a Maritime Infrasound Sensor

Wide global infrasound coverage is obtained using the CTBTO land-based sensing network, whose primary purpose is to detect nuclear test explosions. However, two thirds of the earth's surface is composed of oceans, and no capability yet exists to monitor infrasound signals from sensors fielded in the maritime environment, for example, as hosted by ships, ocean buoys or Unmanned Surface Vehicles (USVs). Such a capability could provide additional infrasound coverage where it is not now present/reliable, or, valuable redundant coverage where it does, thereby improving infrasound event detection confidence, classification, localization, and environmental characterization capabilities worldwide. One of several technical challenges in operating infrasound sensors in the maritime environment is to overcome ocean heave-induced interference. Ocean heave causes interfering ambient pressure fluctuations due to vertical motion of the sensor. This interference may be of significant magnitude to obscure infrasound signals-of-interest. In this paper, we report on an experiment conducted with a microbarometer infrasound sensor deployed onboard a ship at sea. An ocean-heave cancellation method is developed and applied to the collected infrasound data. The results show the performance of this method in cancelling ocean heave-induced interference for infrasound sensors fielded in the maritime environment.

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Track Classification: 3. Data Processing and Station Performance

ID: Type: **Oral**

WIND NOISE LEVEL COMPARISION USING I34MN ARRAY AND MOBILE INFRASOUND STATION

The theory of the infrasound wave propagation states that the acoustic waves of infrasound sources, related with wind and temperature conditions, can be detected at the distance between 200 km and 250 km (McKenna, 2005; Golden et al., 2007). From our seasonal infrasound observations (winter and summer monitoring) and research studies, we would to understand that why some seismo-acoustic waves are detected inside of silence zone (which is located in a distance inferior to 200 km from the source), and to understand the influence of seasons. According to the previous analyzed noise variation of 20-25 dB, we focused to calculate a detail analysis of wind noise level with deployed additional mobile infrasound mini array at the shortest distance of 100km. The purpose of this study is determination level of detection of infrasound waves in the north hemisphere at the distance of 250 km from the source, because of its topography as continental location and altitude with very wind

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Track Classification: 3. Data Processing and Station Performance

ID: Type: **Oral**

Observations of the 13 kt South Atlantic Bolide of 06-Feb-2016.

This year, NASA's Near Earth Object Program reported a 13kt bolide at 13:55 on 06- February-2016 and at 31km above the South Atlantic (30.4◦S, 25.5◦W). Only two IMS stations, both in Antarctica (IS27 and IS55), automatically detected arrivals from this event. These stations are ~4600 and ~8000km from NASA's location, respectively. The arrivals were not automatically associated and are in the IDC's LEB only (the REB requires ≥3 arrivals). The inherent non-uniqueness of the location solution for two stations gives a location >2000km from NASA's and an origin time >2 hours later. Six IMS stations closer to the source than IS27 did not record signals. We re-analyse data for the surrounding IMS stations and use G2S atmospheric profiles for propagation modelling to understand the distribution of observations. Preliminary results suggest the existence of a strong velocity minimum at the tropopause, which generates an elevated waveguide within which the infrasonic energy is trapped. As the stations in Antarctica are approached, the ground temperature lowers, allowing a ground-to-stratospause waveguide to form. This study highlights the difficulties for event association and location with a sparse sensor network and indicates that source altitude may be an important factor to consider when assessing network capability.

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Track Classification: 3. Data Processing and Station Performance

ID: Type: **Oral**

the evaluation of the MUSIC algorithm for the analysis of infrasonic signals

The Multiple Signal Classification (MUSIC) algorithm (Schmidt, 1986) is a well-known high-resolution method used in array processing for parameter estimation. We report on the application of MUSIC to infrasonic data at frequencies applicable to the regional and global explosion monitoring. The infrasonic wavefield is comprised of multiple sources (e.g., microbaroms, anthropogenic noise, mine blasts, etc.) overlapping in time and frequency. The MUSIC algorithm, by analyzing the properties of the covariance matrix, can resolve propagation details with high resolution of multiple co-existing sources. Preliminary results of this study show enhancements in parameter estimation (frequency and direction-of-arrival) with implications for possible improvements in event detection algorithms in cluttered environments.

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Track Classification: 3. Data Processing and Station Performance

ID: Type: **Oral**

infrasound detecting of the massive 2015 Tianjin explosions

A massive explosion in Tianjin erupted at a container port where flammable material was being stored. The explosion produced a mushroom with great shock waves that attenuated gradually and degraded into infrasound in far range. The infrasonic signals were registered by several IMS and domestic infrasonic stations several kilometers away. The signal detection algorithms based on slowness estimation and association algorithms based on signal envelope for the weak and low SNR infrasonic signals are present following a ray-trace processing to discuss the strange signal arrivals earlier than normal. The results of signal processing show that the fore algorithms are effective. The infrasonic signals of the event have a certain amplitudes and fair SNR 3500 kilometers away in downwind direction but cannot be observed clearly several hundred kilometers away in upwind direction. Signal characters of more than 6 sequential signal groups at I34MN, HTI and HMI infrasonic stations are particular compared to the presented explosive infrasonic signals and cannot be explained by the ray tracing even atmospheric profile data from NASA are used show the complexity of modeling of infrasound propagation. The yield of the explosion is estimated in the end that is equivalent to 400-600 tonnes of TNT.

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Track Classification: 3. Data Processing and Station Performance

ID: Type: **Oral**

-GPMCC and DTK-DIVA: New duo of software for infrasound monitoring

Detection capability of infrasound arrays is complex to assess. It is dramatically affected by the background noise, the propagation medium, the array configuration, as well as the type of algorithm used. The completion of IDC event bulletins requires that software be tuned to detect wide variety of signals in broad and well separated frequency bands, often buried in the background with low signal-to-noise ratios. Such high-resolution picking and extraction of signal features guarantee optimum use of the sparse IMS network. It also allows handling the frequency-dependent attenuation along different propagation paths and the highly variable noise conditions from one station element to another. In this context, the number of detections produced depends on the coherent background noise, which often dominates with microbaroms, industrial noise… Large number of detections is not problematic for subsequent network processing (global association, source location) as long as these detections are well and accurately characterized. CEA/DASE has recently developed two software dedicated to infrasound monitoring and packaged in the CTBTO NDC-in-a-box. The combined usage of both tools allow to precisely study signals of interest, provide statistics about the station sensitivity to environmental effects (local meteorological conditions, noise sources…) and understand which parameters affect station detectability.

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Track Classification: 3. Data Processing and Station Performance

ID: Type: **Oral**

Acoustical Impulse Conservation for Estimating a Ground-Level Impulse Source Energy by a Distant Acoustical Method

New methods for estimation the energy of explosions by registration data of infrasound waves are proposed. The one method is based on using acoustical impulse I conservation law - E(I)[kt]= 1.38x 10^(-10)(I[kg/sec])^1.482. Where I is the result of a multiplication wave profile area S/2 of analyzing infrasound signal by a distance to the source. The second method uses correlation between an explosion energy and a duration of N-wave positive phase t on the height of ray tracing turning to the ground - E(t)[kt]=27.67x(t[sec]^2/σ)^(3/2), where σ – some non-dimensional distance characterizes a non-linear effects under sound propagation along ray trajectory. The advantage of the relation E(I) compared to Whitaker‘s relation E(W) is the possibility of using this relation for pulsating sources with any arbitrary profile form of an initial impulse and with any arbitrary type of infrasound arrivals. The peculiarity of E(☒) is obviously taking account of earth atmosphere influence on the characteristics of registration infrasound signals. Both methods are tested by infrasound data, registered in the distance of 322 km from the sources (30 explosions). Empirical relationship between energy values of one and the same explosion is obtained with the different methods: E(I)=1.107×E(W); E(t)=2.201×E(I).

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Track Classification: 4. Modelling & Network Performance

ID: Type: **Oral**

-ACOUSTIC GROUND-TRUTH DATABASE BY KAZAKH NDC DATA

Kazakh infrasound network will consist of three arrays: IS31 Aktyubinsk, Kurchatov and Makanchy when the last one will be opened. Russian infrasound station IS46 Zalesovo is close to our network and its data also may be used for the network processing. There are no many places all over the World when concentration of the infrasound station is the same high. Kazakh NDC automatically detects infrasound signals at IS31-Aktyubinsk, IS46-Zalesovo and Kurchatov arrays records since June 2014 using PMCC. The detection bulletins are input information for the automatic event location. Systematic seismic network data processing takes place for the same region. The processing includes discrimination of the event nature. So there is a big amount of information of instrumental seismic and acoustic observations. This information may be used for the researches of various nature, for the signal propagation modeling etc. These ground truth data may be obtained as a result of seismic and acoustic data fusion. The attempt is made to create such a database. The events at the database are the quarry blasts. Association of the seismic and acoustic event was made in accordance with the technique used at IDC and described at N. Brachet, et al.2010.

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Track Classification: 4. Modelling & Network Performance

ID: Type: **Oral**

the modeling of infrasound waves propagation and estimation of explosion energy of Chelyabinsk meteoroid of February 15, 2013 by the data of seismic and infrasound waves records

The results of infrasound waves propagation modeling for Chelyabinsk meteoroid explosion on February 15, 2013 using the pseudodifferential parabolic equation are shown. The estimation of the explosion location was conducted by analysis of seismic recording near the epicenter. The IS31 located 542 km away of the explosion has recorded 6 infrasound arrivals. The first infrasound arrival from a high-altitude source corresponds to propagation of infrasound "trapped" into near-ground acoustic waveguide channel. Other five infrasound arrivals correspond to propagation in the thermosphere. A vertical profile of effective velocity of sound constructed with the data of satellite measurements was corrected using Nelder-Mead method considering the measured velocities of the infrasound arrivals. A satisfactory agreement of calculation results and experimental data was obtained. The explosion energy of the meteoroid was estimated using two methods. The first applied the property of "acoustic impulse" I conservation. The second method applies the interaction between the explosion energy and duration t of positive phase N – wave at a height of ray tracing turn to the Earth surface. The values in range of 0.5 – 15 kt were obtained for the explosion energy.

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Track Classification: 4. Modelling & Network Performance

ID: Type: **Oral**

propagation-based, stocahstic models for infrasound transmission loss - applications to yield estimation and network performance

Propagation-based, stochastic models for infrasound signal analysis were recently introduced in the context of event localization with promising results. Models for celerity-range and azimuthal variations due to cross winds have been shown to produce improvements in the accuracy and precision of infrasonic source localization estimates. Following this approach, propagation-based, stochastic models for transmission loss of signals have been constructed for applications of estimating explosive yield using infrasonic observations at propagation distances of hundreds of kilometers. Preliminary details of this stochastic yield estimation method will be presented along with an overview of a possible supplemental application to network performance modeling with aim to identify gaps in network coverage using expected seasonal variability in propagation effects.

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Track Classification: 4. Modelling & Network Performance

ID: Type: **Oral**

Wind Effects on Long-Distance Infrasound Amplitude

We have investigated the effects of stratospheric winds on the amplitudes of atmospheric nuclear explosion infrasound signals for distances up to 17500 kilometers. The raw amplitudes data set were scaled for yield. We extracted the zonal and meridional winds from source to receiver propagation path using the Horizontal Wind Model (HWM14) database. An attenuation propagation constant k is derived from the slope of a least-squares best fit by plotting yield-normalized amplitude An and associated wind vector Vd. The k-constant is derived for each infrasound station location and associated testing site location to determine the stratospheric waveguide multiplying factor 10E-kVd. We determine an average k-constant as a function of distance at each nuclear test site location for the wind correction, and find the slopes of the k-constants are on the order of 10E-2 to 10E-3 seconds/meter and are, on average, slightly smaller values to findings by Mutschlecner et al. (1999). Overall, we find that the distance attenuation of the uncorrected-wind amplitude data with respect to distance is not statistically different than the corrected-wind amplitude data, having a standard error of 1.06 and 1.03 respectively.

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Track Classification: 4. Modelling & Network Performance

ID: Type: **Oral**

infrasonic ocean ambient noise

The ability of the International Monitoring System (IMS) infrasound network to detect atmospheric explosions and events of interest strongly depends on station specific ambient noise which includes both incoherent wind noise and real coherent infrasonic waves. To characterize the coherent ambient noise, a broadband array processing was performed with IMS continuous waveform archive from 2007 to 2016 using the Progressive Multi-Channel Correlation algorithm (PMCC). The processing parameters include a new implementation of adaptive frequency dependent window length and a logarithmic band spacing. Such configuration allows to better discriminate between interfering signals with improved accuracy in the wave parameters estimations. Multi-year comparisons between the observed and modeled directional microbarom amplitude variations at several IMS stations using two-dimensional wave energy spectrum ocean wave products are performed to build of a reference database of infrasound oceanic sources. The expected benefits of such studies concern the use of multi-year complementary data to finely characterize coupling mechanisms at the ocean-atmosphere interface. In return, a better knowledge of the source of the ambient ocean noise opens new perspectives by providing additional integrated constraints on the dynamics of the middle atmosphere and its disturbances where data coverage is sparse.

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Track Classification: 4. Modelling & Network Performance

ID: Type: **Oral**

Bayesian model averaging to calibrate atmospheric specifications from infrasound signals

In infrasound propagation modeling, we often face a large number of potential atmospheric models with only a limited number of recorded signals to conduct inference from. Prediction of acoustic signals is a complex issue due to constantly changing atmospheric conditions and to the random nature of smallscale flows (turbulence, gravity waves). Thus, the uncertainty over which model to use for atmospheric specifications is an important aspect of any inference from data. In standard practice data analysts typically select a model from some class of models (G2S, ECMWF, HWM/MSISE, …) and then proceed as if the selected model had generated the recorded signal. Such an approach ignores the uncertainty in atmospheric model selection, leading to overestimated confidence intervals. In the present work, we use Bayesian Model Averaging (BMA) as a a basis for inference about parameters of interest. The Bayesian approach offers a systematic method for checking the robustness of one's results to alternative atmospheric specifications. The method's performance is demonstrated using several events observed through the International Monitoring System (IMS). Our results demonstrate that a bayesian approach together with few atmospheric specifications can improve significantly the posterior distributions of both signal and event characteristics.

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Track Classification: 4. Modelling & Network Performance

ID: Type: **Oral**

-linear infrasound propagation in random atmospheres

Studying the propagation of a waveform throughout a given atmosphere, numerically or theoretically, requires knowledge of wind speed and temperature gradients. A consensus has emerged that the main part of small-scale fluctuations is filtered out of the available data, even though it is known that these fluctuations significantly alter the determined propagative path of the waveform. In most infrasound studies, fluctuations are often represented as a deterministic field that is superimposed on a given background state provided by the G2S-ECMWF climatology. Significant advances have been made in the investigation of linear wave propagation through a perturbed atmosphere, finding realistic application within the infrasound community. In this talk, we will quantify how random subgrid-scale perturbations within a stratified anisothermal atmosphere affects the overpressure and period of a propagating N-wave signal, with application to the propagation of infrasound generated by meteoric activity. Results presented will include bounds on the characteristics of the N-wave in terms of the variation within the given perturbed atmospheric profile. We will show that the cumulative effect of randomness along propagation paths may make the sensitivity of ground-based signals large, in that small changes in the atmospheric specifications can alter significantly the N-wave characteristics.

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Track Classification: 4. Modelling & Network Performance

ID: Type: **Oral**

# of ground-truth events with reduced models

While long-range infrasound propagation modeling is a useful tool in nuclear treaty verification, the inherent unpredictability of subgrid-scale atmosphere dynamics results in a poorly constrained propagation medium. When faced with such a situation it is natural to treat incomplete knowledge within a probabilistic framework and to seek a numerical approach that describes long-range propagation at the lowest numerical cost and complexity. Such a task is rendered complex by the fact that each plausible atmospheric state produces large deviations from the operational numerical weather predictions. In this work, we pursue a new approach, in which propagation modeling is based on reduced-order models provided by the numerical platform FLOWS (Fast Low-Order Wave Simulation). Such models are obtained by retaining a few propagating modes that are confined within waveguides causing the sound to propagate through multiple paths to the receiver. The overall performance of this approach is demonstrated using several ground truth events of specific concern for the verification regime. By examining how the uncertainty manifests statistically within the waveforms, we will show how the use of reduced models in combination with a bayesian approach should help the global infrasound association process.

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Track Classification: 4. Modelling & Network Performance

ID: Type: **Oral**

# of intermittent gravity waves in infrasound signals

Long-range infrasound propagation problems are characterized by both a large number of length scales and correlatively a large number of normal modes. In the atmosphere, these modes are confined within waveguides causing the sound to propagate through multiple paths to the receiver. Even though the accuracy of atmospheric specifications is constantly improving, the main part of gravity waves is still yet not resolved in the available data. In most infrasound modeling studies, the unresolved gravity waves are often represented as a "frozen" disturbance field that is superimposed on a given average background state. Direct observations in the lower stratosphere show, however, that the gravity wave field is very intermittent, and is often dominated by rather well defined large-amplitude and low-probability wave packets. In the present work, we use normal modes to describe both the gravity wave field and the acoustic field. The gravity wave spectrum is obtained by launching few monochromatic waves whose properties are chosen stochastically to mimic the intermittency. We will show that in several realistic situations the cumulative effect of gravity wave breakings makes the sensitivity of ground-based acoustic signals large, in that small changes in the gravity wave parameterization can create or destroy specific acoustic features.

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Track Classification: 4. Modelling & Network Performance

ID: Type: **Oral**

Updated IMS Infrasound Station Noise Models

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Track Classification: 4. Modelling & Network Performance

ID: Type: **Poster**

# of IMS infrasound stations coupled by seismic stations on Chile earthquakes

There are six IMS infrasound stations (IS02, IS08, IS09, IS13, IS14 and IS41) which cover the continental shelf and territory of South America. Two major earthquakes on March 23, 2015 and September 16, 2015 occurred within the territory of Chile that lies within the area covered by these infrasound stations. Using these infrasound stations coupled by seismic stations the two events were analysed. Some of the infrasound stations recorded data that were used to locate the two events while some did not. The probable causes of insufficient data and the results obtained from the analysis are presented in this study.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

stations detection of earthquakes in Ecuador

The IS08 was certified on 20 August, 2002 and IS17 on 9 December, 2002. IS08 contributed recorded data in the study of the earthquake that occurred in Ecuador on 16 April, 2016 while IS17's data was used for the earthquake of 12 August, 2010. The data from these two infrasound stations coupled by that of seismic stations were used to locate both events. This study presents the station performance analysis of these stations on the date of the events and an analysis of both events.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

and Construction of Infrasound Network in Uganda

Ground networks to monitor geophysical processes such as climate change variability and its outcomes such as lightening are inexistent in Uganda. Recently good progress is being made in decision making. Implementation of good decisions can solve negative outcomes of natural processes and can be mitigated to avoid destruction of property and loss of life using science and technology based research. Whereas our efforts relies on Infrasound Data from Nairobi Station (IS32) of the Preparatory Commission for Comprehensive Nuclear Test Ban Treaty organization (CTBTO) in the International Monitoring System (IMS) for civil and scientific application especially in the landslides and lightening studies, there is lack of Local Infrasound Network density in Uganda to improve azimuth solutions. The government of Uganda approved the funds to enable the establishment of five (5) infrasound stations in Uganda to complement the IMS Nairobi Station (IS32) in order strengthen local infrasound network density for research in Uganda and be able to solve the problem the country is now facing.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

Experiment in Indonesia

Abstract Infrasound Experiment in Indonesia Hendri Subakti Scientific collaboration between the BMKG and the CEA in the field of geophysics started in the 1980's, and more recently in the field of infrasound with the installation of the experimental station in Palangkaraya Borneo and Pelabuhan ratu Java also Tondano North Celebes. The volcanic activity is very important in Indonesia where about 129 active volcanoes are counted. Bisides the dramatic aspect of this activity, the Indonesian volcanic Arc offers a potential number of important infrasound sourcesdistributied over time and spaceThe Palangkaraya experiment has clearly demonstrated the potential of infrasound data for monitoring atmospheric changes and source from volcanic activity. After moving to Pelabuhan ratu Java, The infrasound station has been operating in sub optimal conditions, since it is located in a noisy infrasound backround and it small aperture make it very sensitive to any local/regional natural and man made sousce. This is an experiment infrasound in Indonesia pioneer project that would be interesting to continue and develop, furthermore the development of a densified Indonesian network with better positioned station would be much more appropriate for infrasound studies, with for example starting to built a station near Tondano North Celebes.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

based infrasound station design support program with MATLAB

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Primary author: LEE, Seok-tae (KITValley INC.)

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

infrasound and seismic network data for monitoring of explosions in West Africa

Burkina Faso NDC and IDC have worked in the field of seismic and infrasound to conduct investigations of various catastrophes. That's how we carried out investigations into the Ouagadougou explosion and Air Algeria crash respectively on 15 and 24 July 2014 and which allowed us to locate them. In recent years, various studies demonstrate the use of technology valuable infrasound as a complement to existing surveillance networks. Thus, to increase resources nes, participate in various discussions and make our contribution, we are looking for these types of forums to enjoy the experience of others to build our emerging NDC.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

way of modernization of infrasound observation network of Ukrainian NDC

To date, the Ukrainian infrasound observations network requires global modernization and technical re-equipment. To create conditions for compliance with the international practice, Ukrainian NDC plans to carry out work related to improving the characteristics of the two infrasound arrays. The first phase will be significantly expanded arrays aperture and improved characteristics of a noise reducing systems. The dimensions of the aperture will be increased from 130 to 700 meters. Moreover, the all infrasound arrays will be placed inside the protected area. In the second phase, the lower range of infrasonic signals recording will be expanded. To this end, the design parameters microbarographs bandpass filters are modified, and in some cases, exposure of filters on the signal path to be excluded. After this modernization, microbarograph will be able to record signals from atmospheric pressure variations (periods 1 - 10 hours). In this mode microbarograph will be used for registration of small-scale airborne gravity waves and other global long-period signals of natural origin.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

01 Site Survey: Planning, Implementation and Results

While planning the installation of IS01 with the Provisional Technical Secretariat (PTS) late 2015, the Autoridad Regulatoria Nacional (ARN) proposed a plot of land roughly 60 km to the east of Bariloche, Argentina for the station installation. Having been given a set property boundary, the PTS worked to design an optimal array geometry before performing the site survey. As part of a joint effort between the PTS and ARN, an eight element infrasound array was deployed for the month of July 2016, in what would be ideally the final Contact: james.robertson@ctbto.org, equintana@arn.gob.ar installation configuration of the station. We present here a brief summary of the planning, deployment and results of this joint project.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

FOR THE EFFECTIVE UTILIZATION OF THE DATA AND RESOURCES OF THE INFRASOUND VERIFICATION TECHNOLOGY IN THE WEST AFRICAN SUB-REGION

The ability of experts from the emerging NDCs to posses the capability for utilization of the data and products from all the verification technologies constitutes a major step towards the overall success of the CTBT implementation. Currently, there appears to be indicative of serious human and institutional capacity inadequacy within several countries in the West African sub-region in the effective utilization of the available data and resources of the Infrasound verification technology. Within the African continent, Tunisia and some few other African countries have immense knowledge and experience in the infrasound technology analysis capability. We believe that establishing the causes of this inadequacy will greatly assist in bridging this huge knowledge deficiency. More so that in December, 2013 during the NDC Development Workshop in Ouagadougou, Burkina Faso, specific call was made to: 'extend the infrasound measurement background campaigns to cover further regions of interest in Africa'. This provided the impetus for this study which will consider the current status of infrasound verification knowledge, capability of some selected NDCs and availability of experts in the sub-region (West Africa). It will draw from the experience of Tunisia to provide some strategies for bridging this huge gap (e.g. scientific/study visits etc).

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

the knowledge and Understanding of Infrasound Verification Technology through the Utilization of CTBT Educational Resources (CER)

Infrasound Technology is a vital element of the CTBTO's International Monitoring System (IMS) which monitors the globe for compliance with the Nuclear Test Ban Treaty. Understanding this technology and knowing how it works is very critical to the overall performance of the IMS and indeed eventual entry into force of the Treaty. Connecting the public has been a major step taken by the CTBTO to ensure the expansion of the various information and knowledge that will promote open and free education and ensure active participation by Researchers, Scientists, and Civil Societies e.t.c. in the overall implementation of the CTBT. Through the various elements of the CTBT Educational Resources (CER) like the Science and Technology Conference, Open Course archive, Knowledge and Training Platform, Tim Hampton Lecture Series, CTBTO iTunes U (University) page etc the CTBTO is bringing Infrasound Technology education and training to the future generations so as ensure that the international nuclear non-proliferation and disarmament regime remains relevant. The focus of this presentation is to highlight the potential value and benefits of CER in the expansion of Infrasound Technology knowledge and encourage the involvement of the public, particularly the academia, in the utilization CER.

Primary author: BISALLAH, Awwal (Nigeria Atomic Energy Commission)

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

and scientific application of infra sound data at IMS stations in Kenya

Kenya hosts two IMS stations and several seismic station network Having endured, and,after fully addressing the life cycle challenges at both of these stations,we have now embarked on the civil and scientific application of data that is collected by both these stations and sent to both the IDC in Vienna and the NDC-KE in Kenya. The involvement of the government, the local community and the stake holders has helped in maintaining the security of the stations and hence the continued attainment of 98% data availability threshold, standards set by the CTBTO. Educating the community and sharing of the analyzed data from the NDC has led into the participation of both the government and the local community in using the same data for both civil and scientific gains.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

waves generated by chemical explosion at Tian Jin Port, China on 12 August 2015

A large explosion occurred in Tianjin Port, China on 12 August 2015, as a result of an ignition of hundreds tons of explosive material (ammonium nitrate). The explosion generated large amplitude infrasonic signals that were recorded at range of 3.5km-800km. We present an analysis of data using 7 infrasound stations and 3 seismic stations. The infrasound station TJB recorded the infrasonic wave with velocity of 0.747km/s at range of 3.5km from explosion center, which indicates that the wave is blast wave. For the wave traveling longer distance, the velocity of other stations decreases to normal sound speed in atmosphere. The phenomenon of coupling between seismic wave and infrasonic wave from the explosion: seismic wave coupled by local infrasonic wave also was detected in ZJK station (distance 240km) , while infrasonic wave coupled by seismic wave with velocity of 3km/s was detected in BJ stations (distance 150km). The infrasound source localization indicated that these infrasonic waves were probably from explosion center with minimal location error of 15km.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

detection of celestial objects

I. H. Hamama , M. N. ElGabry, H. M. Hussein National Research Institute of Astronomy and Geophysics, 11421 Helwan, Egypt . Infrasound is one of the most important technology which used in detection of surface nuclear explosions. The very low frequency of sound waves are still the secret to detect very far objectives, surface explosion In the early morning of 7th of October 2008, infrasound signals which are related to the explosion of the asteroid TC3, These signal are recorded over 2487 Km in Kenya Infrasound station . In 2013 a small meteor approached to the earth and entered the atmosphere with high speed and destroyed over Chelyabinsk, This event is one of the largest events which is recorded by infrasound technology. On Feb. 6, at about 14:00 UTC, a tiny chunk of interplanetary material plunged into Earth's atmosphere and burned up—likely exploding—about 30 kilometers above the Atlantic Ocean. The energy released was equivalent to the detonation of 13,000 tons of TNT.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

benefits of the infrasound technology to Ghana

The National Data Centers established around the globe with the support of the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO) are used to monitor and manage its data, to control and ultimately eliminate nuclear weapon test explosions. The National Data Center in Ghana was established six years ago to support this course. The Center's mandate is to collate seismic, infrasound, radionuclide and hydroacoustic data for monitoring nuclear test explosions for global peace. Seismic data from the CTBTO are used for seismic hazard studies in the country. The infrasound technology which also has several civil and scientific applications has been introduced at the Center. Research in the field of infrasound would be undertaken using the technology which has vast applications in climate, meteorological, aviation, landslides and lightening studies and blasts from quarry sites, which are very prevalent in Ghana. Keywords: Ghana, National Data Center, Infrasound technology, Comprehensive Nuclear Test-Ban Treaty Organization

Primary author: AMPONSAH, Paulina Ekua (Ghana Atomic Energy Commission)

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

IPLOR infrasound detections for characterization of near-field explosive seismoacoustic sources

National Institute for Earth Physics operates Plostina six-element infrasound array (IPLOR), as well as the dense Romanian Seismic Network (RSN) (over 100 stations). As a result of its sensors' type (Chaparral Physics Model 25) and large aperture (2.5 km), IPLOR array has proven effective in detecting acoustic signals produced by near-field impulsive seismoacoustic sources such as atmospheric, surface and near-surface explosions, or underwater blasts. Most of these sources generate also seismic waves, that can be observed with seismometers (chemical explosions, quarry and mining blasts, seismic air-gun blasting). However, in case of some sources like bolides and thunderstorms, only infrasonic signals are radiated and simultaneously detected by microbarometers and seismometers. Acoustic data recorded with IPLOR were analyzed and combined with RSN seismic observations in an attempt to characterize explosive seismoacoustic events and to distinguish between artificial and natural sources (i.e., explosions from earthquakes). Several seismoacoustic sources observed with IPLOR and RSN stations are presented: accidental explosion in Bulgaria, quarry blast in Dobrogea region, air-gun blasting for oil exploration off the Black Sea West shore, meteorite explosion and local thunderstorm over Plostina region. Surface explosions are useful sources for examination of event location accuracy when seismic and acoustic measurements are jointly processed.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Oral**

signal detected at the Lützow-Holm Bay region, East Antarctica, and their relation to surface environment

A single infrasound sensor has been making continuous recordings since 2008 at Syowa Station (SYO; 69.0S, 39.6E) in the Lützow-Holm Bay (LHB) of East Antarctica. The continuously recorded data clearly show the contamination of background oceanic signals (microbaroms) throughout all seasons. In austral summer 2013, several field stations with infrasound sensors were established along the coast of the LHB. Two infrasound arrays of different diameters were set up: one at SYO (with a 100-m spacing triangle) and one in the S16 area on the continental ice sheet (with a 1000-m spacing triangle). In addition to these arrays, isolated single stations were deployed at two outcrops in the LHB. Detailed and continuous measurements of infrasonic waves in Antarctica could prove to be a new proxy for monitoring regional environmental change as well as temporal climate variations in high southern latitudes. Until now, these arrays clearly detected the propagation direction and frequency content of microbaroms from the Southern Ocean. In addition to the microbaroms, several other remarkable infrasound signals were detected, including regional earthquakes, the calving of icebergs and glaciers, and so on. In this presentation, we would introduce detected infrasound signals.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Oral**

effect on MAWs from Drakensberg Mountain using IS35 and IS47

IMS Infrasound stations detect mostly signals from Mountain Associated Waves at frequency range [0.015 - 0.1Hz]. MAWs are generated as hydrodynamic oscillation in the turbulent wind-stream in the lee of high mountain ranges (Meecham, 1971). Drakensberg mountain located in SouthAfrica is used as source for studying the amplitude attenuation (Bass & Sutherland, 2003) at two infrasound stations IS47, South Africa and IS35, Namibia. PMCC (Cansi, 1995) is used to process infrasound data. ECMWF (from CTBTO) and HWM07/NRLMSISE00 atmospheric models are used in the acoustic propagation through the atmosphere and attenuation are achieved with Finite Difference Time-Domain (C. De Groot-Hedlin, 2008) and hamiltonian raytracing (Virieux, 2004). IS47 detects signal from Drakensberg Mountain almost over the year. However with IS35, this source is observed only from December to March and from June to July. In first approximation, amplitude is decreasing with range however amplitude is higher than its trend on stratospheric arrival.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

application of local seismic and infrasound networks as national technical mean

In this study, some local networks of Iran are presented and their activity compare with regional networks are shown emphasizing the remarkable natural difference of seismic activity detection. Seismic networks are and will be probably forever the only tool that enables study of the detailed structure and physical properties of the Earth. Local instruments could be a useful mean while going into depth in an area. Local seismic networks could effectively use checking seismic activity of any area with highest resolution and precision. Lots of small events couldn't record on global networks and the magnitude of completeness of local network catalogs are always less than regional or global ones which is a great advantage of these kind of networks as national technical mean. The detecting ability simply changes with instrumental coverage which plays an effective role for professional and applied usages in seismology. The inherent error in regional and global networks are as high that can't give accuracy to determine the exact trend and depth of seismic sources and enough evaluation for early warning networks and rapid response systems which can effectively reduce the natural hazard of earthquakes. Many local networks are operating for various goals of seismology in Iran and this definitely will increase the quality of studies and can prepare lots of informative data that directly relates to seismic hazard assessment. These networks have reduced the magnitude of completeness of seismic catalogs and increase the knowledge of crustal properties which will prepare a huge data bank to define realistic 2D, 3D earth models. Infrasound networks are one of the other local networks that we could have. We could use infrasound networks in south-east of Iran, Makran region. Makran is one of the important subduction zone. We could detect interfering oceanic waves if we have Infrasound network in this region.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

Local and regional infrasound sources detected by IS17

The analysis of local and regional sources of infrasound emission was done using the new software DTK-MCSP and DTK-DIVA provided by the CTBTO. The sources were studied in 2009-2016.
The analysis showed two (2) frequency bands emission from these sources: 3.0-1.0Hz and 0.3-0.1Hz respectively for high and low frequencies. The different sources detected can be divided into two (2) groups according to their azimuth.
The first group emit infrasound with a constant azimuth throughout the study period (80°, 100°, 120°; and around 150° and 250°). These emissions are high frequency (3.0-1.0Hz) and are independent of high-altitude wind fields. These sources indicate mainly industrial areas. The second group is detected with three azimuth angles around: 200°; 270° and 330°. These sources are low frequency (0.3-0.1Hz) and have a seasonal cycle. The sources with 200° and 330° azimuth appear to come from the south and north of Atlantic ocean respectively. These sources can be the Atlantic ocean swells. The source of 270° azimuth derived from the mountainous region west of Cote d'Ivoire.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

technology in Indonesia: 2015 Eventful year review

Infrasound technology has been developing rapidly in the last 15 years and is now reaching a level of maturity that justifies deploying infrasound stations for monitoring geophysical phenomena. Infrasound stations are being deployed worldwide, for both scientific and societal applications. BMKG and CEA have extended their collaboration to set-up experimental infrasound stations across the Indonesian Archipelago. One station is located in Pelabuhan Ratu, West-Java. Although this array is located in a noisy infrasound background and its small aperture makes it very sensitive to local sources, the experiment provides useful information. On a long time scale, data are collected, and processed using adapted correlation-based methods in order to detect coherent signals in the background noise. Data processing focuses on one full year of measurements and are compared with products provided by the International Monitoring System (IMS) or by geophysics institutes like BMKG for earthquakes or the Smithsonian Institution for volcanic eruptions. We demonstrate the potential of such an experimental station by placing greater emphasis on several successful and significant infrasound detections of the year 2015. In that context, infrasound data, coupled with conventional measurements, help characterizing and quantifying acoustic sources. Of specific interest is the characterization of seismo-acoustic events using infrasound. Such long-range monitoring may help to prevent eruption disasters, mitigate ash clouds with strong implication for aviation hazard, the monitoring of large earthquakes or atmosphere dynamic parameters.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Oral**

3-D acoustic wavefield observations and modeling at Yasur Volcano, Vanuatu using a dense infrasound network

Sampling of volcano seismic and acoustic wavefields have traditionally been limited to two dimensions due to the surrounding topography. However, volcano seismo-acoustic sources are known to be anisotropic and the resultant waves strongly influenced by crater morphology and topography. Between 26 July – 2 August 2016 we deployed a dense network of seismic and infrasonic sensors at the very active Yasur Volcano, Vanuatu to overcome these wavefield sampling limitations. Notably, two infrasound sensor packages were deployed on tethered balloons above the active vents. Additionally, 6 single infrasound sensors were deployed close to the vent along the crater rim, along with 7 small-aperture, 3-element infrasound arrays and 11 broadband seismometers. Extensive visual and infrared imagery was taken, as well as measurements of gas composition and flux. Here we discuss the preliminary results from this experiment and highlight future work on the dataset. Volcanic activity was high during the period with high-amplitude explosions occurring every 1-5 minutes. Extensive shock waves were recorded both visually and acoustically. Results from numerical modeling of the acoustic wavefield integrated with a high-resolution digital elevation model will also be compared to observations.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

effects of the Khubsugul earthquake of December 5, 2014, Mw = 4.9, Mongolia

Seismoacoustic effects of the Khubsugul earthquake of December 5, 2014 (51.37N, 100.63E, MW=4.9) were studied. Earthquake occurred in the Khubsugul basin at the depth 3 km. Acoustic signal was registered by the infrasound station "Tory" located at the distance 175 km from the epicenter. Travel time of acoustic waves is about 280 s. Apparent velocity of infrasound signal propagation is ~625 m/s. We assumed that the epicentral area may not be acoustic wave radiation source and modeled the signal partly as a seismic and partly as an acoustic. For the calculations velocity of acoustic waves was assumed to be 300 m/s and seismic P-waves – 6.15 km/s. According to the calculations, the emergence of acoustic waves in the atmosphere are expected to 80-85 km radius from the receiver. On the trace "source-receiver" these distances correspond to the northern slope of the Khamar-Daban ridge (southern board of the Turan depression). The difference in height here is 1700 meters. It can be concluded that infrasound signal was radiated by the slope of the mountain ridge, and the high apparent velocity of acoustic waves is explained by the fact that the signal is propagated in the crust as seismic.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Oral**

, medium and long-range infrasound observations of Etna volcano, Italy.

Volcanoes are efficient sources of infrasonic waves that can travel large distances (>1000 km) in atmospheric waveguides with very limited amplitude loss. In favourable propagation conditions, long-range infrasound well tracked the occurrence and the duration of volcanic eruptions: yet, the potential of infrasound technology to infer the fine details of the volcanic eruptive source is still under debate. We compare short, medium and long-range infrasound observations of eruptive activity at Etna volcano as recorded by infrasound arrays deployed at local (~5 km), regional (~630 km) and larger distances (IMS CTBT Infrasound Network) from the source. Activity at Etna volcano increased since 2011, with more than 50 lava fountains episodes until May 2016, able to produce 1-2 km high sustained lava columns and feeding ash column reaching heights of more than 10 km. Local, regional and far-field infrasonic features are investigated and compared with available information on the plume height. The potential of near real-time notification of ongoing volcanic activity at Etna volcano is discussed. This work is performed in the framework of the EU H2020 ARISE2 project (2015-2018) and in the framework of the vDEC collaboration established with the Provisional Technical Secretariat of the Comprehensive Nuclear-Test-Ban Treaty Organization.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Oral**

waves as means to monitor tropospheric weather and crater morphology changes

We use infrasound waves generated by volcanic eruptions at Volcan Tungurahua to study both changing atmospheric conditions and source characteristics. Analyzed infrasound data were recorded for a 32 month period at Volcan Tungurahua by a five-station network (within 6.5 km from the vent). We use cross-network correlation to quantify the cyclic eruptive behavior of Tungurahua and results are corroborated by reports from the Ecuadorian monitoring agency. Cross-network correlation lag times are used to compute ~6.75 m resolution infrasound source positions, which take into account coarse NOAA atmospheric models for local winds and temperatures. Variable infrasound-derived source locations suggest source migration during the 32 months of analyzed data. Such source position variability is expected following energetic eruptions that destructively altered the crater/vent morphology as confirmed by imagery obtained during regular overflights. We also observe variations in cross-network lag times over short time periods (seconds to days) when vent location is stable and attribute these variations to changes in atmospheric structure. Assuming a fixed source location we invert for average air temperatures and winds in Tungurahua's vicinity (<6.5 km) and find evidence for diurnal and semidurnal tropospheric tides.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Oral**

Infrasound Station IS41 “Villa Florida Paraguay”

IMS Infrasound Station IS41 “Villa Florida Paraguay” was installed and certified in 2003 is operated by the National University of Asuncion. During the last years the station started to experience several technical problems and data transmission to Vienna was interrupted from weeks to months resulting in station non capability. Anyhow Paraguay NDC with IMS data and IDC products focus on the infrasound technology for a better understanding of the signal recorded by IS41 and regional Infrasound stations for characterization and identification of events sources.

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Track Classification: 5. Analysis of Sources and Scientific Applications

ID: Type: **Poster**

# of Infrasound events listed in IDC Reviewed Event Bulletin

Until 2003 two waveform technologies, i.e. seismic and hydroacoustic were used to detect and locate events included in the International Data Centre (IDC) Reviewed Event Bulletin (REB). The first atmospheric event was published in the REB in 2003, however automatic processing required significant improvements to reduce the number of false events. In the beginning of 2010 the infrasound technology was reintroduced to the IDC operations and has contributed to both automatic and reviewed IDC bulletins.

The primary contribution of infrasound technology is to detect atmospheric events. These events may also be observed at seismic stations, which will significantly improve event location. Examples sources of REB events, which were detected by the International Monitoring System (IMS) infrasound network were fireballs (e.g. Bangkok fireball, 2015), volcanic eruptions (e.g. Calbuco, Chile 2015) and large surface explosions (e.g. Tjanjin, China 2015).

Query blasts (e.g. Zheleznogorsk) and large earthquakes (e.g. Italy 2016) belong to events primarily recorded at seismic stations of the IMS network but often detected at the infrasound stations. In case of earthquakes analysis of infrasound signals may help to estimate the area affected by ground vibration. Infrasound associations to query blast events may help to obtain better source location.

The role of IDC analysts is to verify and improve location of events detected by the automatic system and to add events which were missed in the automatic process. Open source materials may help to identify nature of some events. Well recorded examples may be added to the Reference Infrasound Event Database to help in analysis process. This presentation will provide examples of events generated by different sources which were included in the IDC bulletins.

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