Infrasound Technology Workshop 2015 (ITW2015)

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; - separating infrasound data from other waveform technologies at the automatic network processing stage for technology development and for preparing the implementation of next generation of waveform association algorithm. Infrasound rules in Global Association (GA) and NET-VISA implementation are explored to pursue a lower ratio of false alarms; - network capability estimations as a tool to monitor performances. The IDC identified a number of areas for improvement of its infrasound system, those will be shortly introduced.

Primary author: MIALLE, Pierrick (CTBTO Preparatory Commission)

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) consists of sixty stations, including forty-seven certified stations transmitting continuous data to the International Data Centre (IDC) in Vienna, Austria. Each infrasound station is composed of an array of infrasound sensors capable of measuring micropressure changes produced at ground level by infrasonic waves. The Provisional Technical Secretariat (PTS) of the Comprehensive Nuclear-Test-Ban Treaty (CTBTO) is continuously working towards the completion and sustainment of the IMS infrasound network. The objective of this presentation is to review the main activities performed in the IMS infrasound network over the last year. This includes construction, installation, certification, major upgrade and revalidation activities. Major technology development projects to improve the reliability and robustness of IMS infrasound stations as well as their compliance with IMS Operational Manual requirements will also be highlighted.

Primary author: MARTY, Julien (CTBTO)

Presenter: MARTY, Julien (CTBTO)

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

ID: Type: **Oral**

IMS Infrasound Stations: Issues of Operation and Modernization

The Comprehensive Nuclear-Test-Ban Treaty was ratified by the Russian Federation on 30 June 2000. According to the Treaty there are four IMS infrasound stations in Russia, which are located in Dubna (IS43), Petropavlovsk-Kamchatskiy (IS44), Ussuriysk (IS45) and Zalesovo (IS46). During operation Russian IMS infrasound stations there are different problems, such as flooding of station's equipment, necessity of using special transport to achive some sites, absence of spare digitizers and microbarometers because of shipment problems to RF etc. The solution of some issues can be simplified with using equipment produced in RF. For example, microbarometer ISGM-03M, which was developed by Scientific Technical Center "Geophysical Measurements" (Novosibirsk, Russia). Microbarometer ISGM-03M meets PTS certification requirements. Calibration of microbarometer can be provided with the aid of automated equipment ISCGM-2. The use of this microbarometer will make it possible to reduce time of repair and alleviate logistic and customs problems.

Primary author: DEMIAN, Evgenii (Special Monitoring Service (SMS) of the Ministry of Defense)

Presenter: DEMIAN, Evgenii (Special Monitoring Service (SMS) of the Ministry of Defense)

Track Classification: 2. Infrasound Instrumentation

ID: Type: **Oral**

# of Meteorological Observations at IMS Infrasound Stations

The 2012 Infrasound Expert Group Meeting Report includes number of recommendations to the improvement of meteorological observations at CTBTO / International Monitoring System (IMS) infrasound stations, including investigation of the possibility of IMS observations to get closer to to World Meteorological Organization (WMO) standards, use of absolute pressure sensors at infrasound stations instead of MB2005 absolute pressure data and decreasing meteorological data sampling. The Engineering and Development Section of the IMS presents the results of following the recommendations of the report, containing study of the WMO requirements and their applicability to IMS standards and practice, first installations of absolute pressure sensors, quality improvement of meteorological data and implementation of State-Of-Health monitoring software.

Primary author: MARTYSEVICH, Pavel (CTBTO)

Presenter: MARTYSEVICH, Pavel (CTBTO)

Track Classification: 2. Infrasound Instrumentation

ID: Type: **Oral**

station : Renewal considerations

On the French Polynesian infrasound station I24FR, the wind noise reducing system is based on an 18 m diameter star array with 32 low impedance inlets. In the framework of the station upgrade, the question to use 96 air inlets instead of 32 air inlets is tackled. Global assessment on performances, investment and maintenance will be considered with respect to WNRS.

Primary author: MILLIER, Philippe (CEA - Commissariat à l'énergie atomique et aux énergies alternatives - Département analyse, surveillance, environnement)

Presenter: MILLIER, Philippe (CEA - Commissariat à l'énergie atomique et aux énergies alternatives - Département analyse, surveillance, environnement)

Track Classification: 2. Infrasound Instrumentation

ID: Type: **Oral**

# of Distributed Infrasound Sensor Networks

Infrasound sensor and array networks on the ground and aloft permit acoustic remote sensing for diverse natural and man-made events. This paper discusses the evolution of monitoring systems for both natural and man made hazards, including (but not limited to) volcanoes, earthquakes, tsunamis, typhoons, explosions, and industrial accidents.

Primary author: GARCES, Milton (Defense Threat Reduction Agency, Nuclear Arms Control Technology Program)

Presenter: GARCES, Milton (Defense Threat Reduction Agency, Nuclear Arms Control Technology Program)

Track Classification: 2. Infrasound Instrumentation

ID: Type: **Oral**

Interlaboratory Comparison Study - Process and main results

The Pilot Interlaboratory Comparison Study (the "Pilot Study") was initiated based on recommendations of the Infrasound Expert Group Meetings 2013 and 2014. The scope of the Pilot Study includes the review of the state-of-the-art methods used in the characterization, testing and evaluation of infrasound sensors with the long-term objective of performing Interlaboratory Comparisons. The Pilot Study Group includes three Participants (CEA, SNL, UMiss) and one Coordinator (PTS). In this work, we present the scope and the process of the Pilot Study, including the agreed upon definitions of quantities measured (Self-noise, Dynamic Range, Sensitivity, Frequency Response and Passband), the Technical protocol and the circulation of a set of sensors between Participants. Preliminary results of the Pilot Study will also be discussed based on reports from Participants.

Primary author: DOURY, Benoit (CTBTO)

Presenter: DOURY, Benoit (CTBTO)

Track Classification: 2. Infrasound Instrumentation

ID: Type: **Oral**

Duration Wind Noise Abatement Study at the University of Mississippi Field Station

Long duration measurements have been obtained at the University of Mississippi Field Station. These tests compared bare sensors to sensors treated with porous hoses, and sensors under circular domes of different diameters (1.15, 1.50, 2.40 and 6.00 m). The domes used a variety of external claddings, including 2.5cm thick foam and perforated aluminum meshing (typically the holes had a diameter of 3mm, with a 5 mm spacing and 30% effective opening). The sensors were recorded continuously, allowing measurements to be obtained over a wide range of weather conditions. As expected, the frequency of maximum wind noise attenuation decreased with increasing diameter of the dome, and the maximum attenuation obtained increased commensurately with diameter. Tests were also performed with nested domes, which were shown to provide greater attenuation than just the larger of the two domes. While porous horses typically provided superior wind noise attenuation at lower frequencies, these also attenuated sound at higher frequencies, and there were number other issues (temperature dependence of the transfer function, pores getting clogged in rainy weather), which made them less than ideal for longer period unattended observation.

Primary author: TALMADGE, Carrick (University of Mississippi/NCPA)

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Track Classification: 2. Infrasound Instrumentation

ID: Type: **Oral**

Approach towards IMS Equipment and Service Contracts (Call-Offs)

Together with the guidance of the PTS 2014-2017 Midterm Strategy, IMS Operational Manuals and historical experience throughout the IMS, IMS/ED has begun an earnest and well planned effort to improve the quality of future equipment and services support contracts. In order to benefit IMS stations, targeted engineering contracts include intra site communications, station power systems, grounding/lightning protection and data acquisitions systems. With these future contracts, along with the recently implemented Wind Noise Reduction System contract, IMS/ED will focus on both the supply of quality goods and the sourcing of reliable services, all in an effort to continually improve existing and planned IMS stations.

Primary author: ROBERTSON, James Stuart (CTBTO)

Presenter: ROBERTSON, James Stuart (CTBTO)

Track Classification: 2. Infrasound Instrumentation

ID: Type: **Oral**

Power Supply Problems at IMS Infrasound Stations

A large number of IMS infrasound stations are installed at remote locations without reliable grid coverage and stable power supply. One of the commonnly used sources of electricity is photovoltaic system and battery bank. Although the use of solar energy is not a new concept, there are no off-the-shelf packages ready to be deployed at all the stations. In addition, complicated access and logistics, equipment failure and difficult weather conditions are among the challenges that we have to overcome during the operation and maintenance of the stations. This paper describes the installation and maintenance of the power supply systems at some IMS infrasound stations, where the installations were adapted to the particular local conditions, allowing reliable power source, efficient remote monitoring, operation and maintenance.

Primary author: STEFANOVA, Stefi (IMS/MFS)

Presenter: STEFANOVA, Stefi (IMS/MFS)

Track Classification: 2. Infrasound Instrumentation

ID: Type: **Oral**

noise reducing system: complementary results

In the framework of incoming IS stations recapitalization, it is mandatory to improve our knowledge on wind noise reducing system. For that, some simulations and on field experiments were carried out. The results are discussed according to different multi inlets configurations. These elements will provide some useful information in the choice of the future new WNRS.

Primary author: MILLIER, Philippe (CEA - Commissariat à l'énergie atomique et aux énergies alternatives - Département analyse, surveillance, environnement)

Presenter: MILLIER, Philippe (CEA - Commissariat à l'énergie atomique et aux énergies alternatives - Département analyse, surveillance, environnement)

Track Classification: 2. Infrasound Instrumentation

ID: Type: **Oral**

in the integration of onsite calibration capability at IMS stations - Towards measurement quality assurance

In the report of its 43rd session published in September 2014, Working Group B tasked the PTS to integrate a passive calibration technique based on side-by-side comparison into the IMS infrasound network. IS26 (Freyung, Germany) was selected as a pilot station, and the technique was installed there in May 2015. In this work, we present the integration of the calibration technique at IS26. We then discuss the need for Measurement Quality Assurance, a set of processes, methods and procedures that will allow one to ensure that the calibrations we perform meet IMS quality management criteria. This entiles the allowable limits of measurement error, the reference base to which the measurements must be related, the properties of the measurement process and a means of assigning uncertainty to our measurements.

Primary author: DOURY, Benoit (CTBTO)

Presenter: DOURY, Benoit (CTBTO)

Track Classification: 2. Infrasound Instrumentation

ID: Type: **Oral**

# of infrasound in-situ calibration method on a 3-month measurement campaign

This work is devoted to the signal processing algorithm developed for the on-site calibration of infrasound stations in accordance with the draft IMS operational manual. This algorithm is based on the comparison of the spectral contents between the sensor under test and a known reference sensor. However because the large signal variability, mainly due to the wind effects, the requirements are very challenging. The presented study has led to use a log-scale filter bank approach and a weighted estimator based on the coherence level. The algorithm as well as the numerical results obtained for several weeks of measurements at IS26 (Germany) will be presented. The results confirm the capability of the method to provide results within IMS minimum requirements. It also appears that the method is able to provide useful information on the performance and response of the noise reduction system.

Primary author: CHARBIT, Maurice (Telecom-ParisTech)

Presenter: CHARBIT, Maurice (Telecom-ParisTech)

Track Classification: 2. Infrasound Instrumentation

ID: Type: **Oral**

39PW Real-Time Station Performance Monitoring

The collection of usable infrasound station data is a pragmatic performance requirement. Infrasound array I39PW, Palau, is located near the Asian-Pacific Ring of Fire and within the Northwestern Pacific typhoon basin. These natural source regions provide abundant ambient signals for assessing station performance and streamlining processing routines. The University of Hawaii Infrasound Laboratory (ISLA) operates and maintains I39PW and runs several automated processes for real-time station performance monitoring. The Infrasonic Energy, Nth Octave (INFERNO) framework is used to select the frequency bands and time windows used in real-time spectral analyses, signal to noise, and PMCC4 array processing. Selected case studies will be presented.

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Track Classification: 3. Infrasound Data Processing and Station Performance

ID: Type: **Oral**

the association of infrasound events using a probabilistic categorization of clutter.

The IDC collects waveforms from a global network of infrasound sensors maintained by the IMS, and automatically detects signal onsets and associates them to form event hypotheses. However, a large number of signal onsets are due to local clutter sources such as microbaroms (from standing waves in the oceans), waterfalls, dams, gas flares, surf (ocean breaking waves) etc. These sources are either too diffuse or too local to form events. Worse still, the repetitive nature of this clutter leads to a large number of false event hypotheses due to the random matching of clutter at multiple stations. Previous studies, for example [1], have worked on categorization of clutter using long term trends on detection azimuth, frequency, and amplitude at each station. In this work we continue the same line of reasoning to build a probabilistic model of clutter that is used as part of NET-VISA [2], a Bayesian approach to network processing. References: [1] Infrasound categorization Towards a statistics-based approach. J. Vergoz, P. Gaillard, A. Le Pichon, N. Brachet, and L. Ceranna. ITW 2011 [2] NET-VISA: Network Processing Vertically Integrated Seismic Analysis. N. S. Arora, S. Russell, and E. Sudderth. BSSA 2013.

Primary author: ARORA, Nimar (Bayesian Logic, Inc.)

Presenter: ARORA, Nimar (Bayesian Logic, Inc.)

Track Classification: 3. Infrasound Data Processing and Station Performance

ID: Type: **Oral**

and studying of local infrasound coupled by seismic wave on wide spread infrasound network

A kind of least-squared-error localization algorithm applied on wide spread infrasound network is proposed in this article. Model of cross correlation between distant sensors and atmosphere infrasound propagation are analyzed. The localization error caused by quantity and distribution structure of network and ray tracing of local infrasound in real atmosphere are also calculated. Infrasound coupled by local seismic Rayleigh wave of Lushan (Ya'an) Earthquake on April 20th 2013 is detected by infrasound network and could prove the algorithm and analysis above. Comparing infrasound signals with seismic recording of IRIS global network, we found that they were well correlated for the corresponding time period in signal travel time, signal correlation (0.6-0.9), particle motion trajectory analysis, etc. the zone of infrasound source calculated by the least-squared-error localizing algorithm is not compact but its center (minimum value determined by least-squared-error method) is less than 150km distant from the epicenter. Due to the less absorption and refraction in atmosphere propagation, local infrasound is easily detected and recognized and could be a possible and feasible way to monitor earthquake.

Primary author: GUO, Quan (Institute of Crustal Dynamics, Chinese Earthquake administration)

Presenter: GUO, Quan (Institute of Crustal Dynamics, Chinese Earthquake administration)

Track Classification: 3. Infrasound Data Processing and Station Performance

ID: Type: **Oral**

Infrasound Network Detection and Association

We apply infrasound pipeline processing algorithms to multiple years of International Monitoring System infrasound data. The results are summarized to identify trends in detection bulletins at each IMS infrasound array. Automatically formed events are compared with the CTBTO Reviewed Event Bulletin for the same time period. By identifying both false positives and false negatives, we identify improvements that are required to automatic algorithms.

Primary author: ARROWSMITH, Stephen (Southern Methodist University)

Presenter: ARROWSMITH, Stephen (Southern Methodist University)

Track Classification: 3. Infrasound Data Processing and Station Performance

ID: Type: **Oral**

# of coherence influence on the detection capabilities of the IMS network

The loss of coherence in the infrasonic arrays have been introduced by Mack & Flinn (1971) and have since been heavily studied (Blandford, 2002) , (Nouvellet, 2013), (Green, 2013). The loss of coherence (LOC) is derived from uncertainties on the source wavefront. This leads to a loss of coherence that is function of both the distance between the sensors, and the frequency. In this study, we propose an algorithm to simulate the LOC which is used to compute the performance of the usual detectors (consistency, MCCM, F-Detector) in presence of loss of coherence. We show that in case of strong LOC, the choice a small subset of sensors can increase the detection capabilities of a IMS station. However, in case of strong noise it is recommended to use the maximum number of sensors for the detection. We finally give a strategy to select the optimal subset of sensors based on the amplitude of the loss of coherence and the SNR.

Primary author: NOUVELLET, Adrien (1CEA/DAM/DIF)

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Track Classification: 3. Infrasound Data Processing and Station Performance

ID: Type: **Oral**

infrasonic signals with very low frequency

The problem of identification of infrasonic signals with frequency (0.002-0.02 Hz) was studied. Such infrasonic signals can be obtained from atmospheric storms. Signals amplitudes comparable with a noise. The data obtained from IMS station IS 43 were analyzed. Two identification methods of infrasonic signals were used. The first based on the Fourier and morphological analysis and the second based on correlation analysis. The obtained direction of arrival for the selected infrasound signals were compared with the direction of propagation of atmospheric fronts. Weather maps of atmospheric fronts were presented as well. The quite good correlations between calculated direction of infrasonic arrivals and that ones for atmospheric fronts was observed.

Primary author: TSYBULSKAYA, Nadezda (A.M. Obukhov Institute of Atmospheric Physics)

Presenter: TSYBULSKAYA, Nadezda (A.M. Obukhov Institute of Atmospheric Physics)

Track Classification: 3. Infrasound Data Processing and Station Performance

ID: Type: **Oral**

# of Infrasound Events Location and Source Discrimination in Central Eurasia Region

Kazakh NDC provides infrasound signal detection and event localization since 2013. Data come from a network consisting of two Kazakhstani infrasound arrays IS31 and Kurchatov and also Russian station IS46. Construction of another infrasound array at Kazakhstan is at the final stage. It is at the East of Kazakhstan. The station collocates with seismic array at Makanchy, PS23. For the moment event bulletins are available for almost three years of observations. Analysis of these data allows to extract regions with high density of infrasound sources. It is possible to study seasonal changes at the network detectability. Initial discrimination of some frequently acting sources is resolved. Unseasonable detectability changes are also preliminary explained.

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Presenter: SMIRNOV, Alexandr (Kazakhstan National Data Centre)

Track Classification: 3. Infrasound Data Processing and Station Performance

ID: Type: **Oral**

a Probabilistic Infrasound Detection Scheme using the Hough Transform

Due to the sparse nature of the 60 station International Monitoring System (IMS) infrasound array network, correctly associating multiple signals with an acoustic source is challenging. The process is made more difficult by detection schemes that struggle to distinguish between small local sources and the large distant sources of interest to the Comprehensive Nuclear-Test-Ban Treaty Organization. At telesonic distances (>1000km) signals from point explosions appear to have stable backazimuths and long durations (hundreds of seconds). One detection scheme that exploits both the backazimuth stability and the long signal duration is the Hough Transform detector (applied to infrasonic data by Brown et al., 2008). This detector scheme takes a series of short-window estimates of signal backazimuth and identifies linear features consistent with long duration stable signals. To assess the quality of a detection we apply a probabilistic framework, developed by the radar community, to construct a combined F-statistic and Hough transform detector. The F-detector provides the initial backazimuth estimate, while the Hough transform exploits the signal duration and stable backazimuth. Examples are shown of applying the scheme to IMS data, and the suitability of the probabilistic framework for long-range infrasound detection is discussed.

Primary author: GREEN, David (AWE Blacknest)

Presenter: GREEN, David (AWE Blacknest)

Track Classification: 3. Infrasound Data Processing and Station Performance

ID: Type: **Oral**

Years of Infrasound Arrivals in the International Data Center Bulletins: A Review

Infrasound re-entered automatic processing at the International Data Center, Vienna, on 11th February, 2010. This presentation provides a review of the infrasound arrivals that have been incorporated into the automatically generated Standard Event Lists (SEL's) and the analyst-reviewed Reviewed Event Bulletin (REB) over the past five years. The analysis focuses upon events in western Eurasia; significant numbers of events are recorded in this region, in part due to a higher density of International Monitoring System (IMS) infrasound arrays. In particular we focus upon the geographical clustering of events that contain only infrasound arrivals (and not seismic arrivals). One example is an analysis of an event cluster within the REB over the North Sea, a known area of sonic boom generation. Data recorded across the LOFAR microbarograph network in the Netherlands provides a method of comparison between arrivals recorded across the sparse IMS network with data recorded at near-regional ranges (<600km). We also examine the relationship between the arrivals that are automatically associated in the SEL3 and those arrivals that pass analyst-review and enter the REB.

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Presenter: GREEN, David (AWE Blacknest)

Track Classification: 3. Infrasound Data Processing and Station Performance

ID: Type: **Oral**

global view on the coherent infrasound field

Systematic characterization of coherent infrasound detection is important for quantifying the recording environment of each station which influence the detection probability of specific signals of interest. We present results of global coherent infrasound measured at IMS infrasound stations and its correlation with atmospheric dynamics. The processed database covers the time period from 2005 to 2015; whereas the number of stations has increased from 30 to 48. Following Matoza et al. (2013), the new implementation of the Progressive Multi-Channel Correlation (PMCC) algorithm enables the characterization, with a single processing run, of coherent noise in the log-spaced frequency bands from 0.01 to 5 Hz. Such experiment enables a better characterization of all received signals (e.g. frequency, azimuth, trace velocity). This, in-turn, allows more accurate signal discrimination, source and propagation studies. The multi-year processing so far indicates a continuous spectrum of coherent signals. It emphasizes continuous signals such as mountain associated waves, oceanic microbaroms, as well as persistent transient signals such as repetitive volcanic, surf, thunder, or anthropogenic activity. From these results, coherent ambient infrasound detection models station, frequency and time dependent could be derived and used to make more accurate and realistic network detection capability models.

Primary author: LE PICHON, Alexis (CEA/CENTRE Ile-de-France)

Presenter: LE PICHON, Alexis (CEA/CENTRE Ile-de-France)

Track Classification: 3. Infrasound Data Processing and Station Performance

ID: Type: **Oral**

, the Korea Seismo-Infrasound Array installed at PS31

Korea Institute of Geoscience and Mineral Resources (KIGAM) has installed an infrasound sensors since May 2014 on the existing eight seismic stations of PS31 called KSRS which is composed of 26 seismic sensors with a 40-km aperture. The installed acoustic sensors are collocated with the seismic stations of KSRS. This changes part of KSRS into a seismo-infrasound array, the Korea Seismo-Infrasound Array (KSIAR). The aperture of KSIAR is 6.8 km. The data from KSIAR except that from the site KS06 is being transmitted in real time to KIGAM with VPN and internet line. The analysis on seismo-acoustic signals has been performed since the installation of acoustic gauges. The utilization of an array process called Progressive Multi-Channel Correlation (PMCC) detects seismo-acoustic signals caused by various sources including small explosions in relation to constructing local tunnels and roads as well as large scale surface explosions in regional distance ranges. The seismo-acoustic signals recorded by KSIAR are supplying useful information for discriminating local and regional man-made events from natural events.

Primary author: KIM, Tae Sung (Korea Institute of Geoscience and Mineral Resources (KIGAM))

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Track Classification: 3. Infrasound Data Processing and Station Performance

ID: Type: **Oral**

explosion observed by the US-ARRAY : an unprecedented collection of infrasound phases recorded from the same event

The 28th October 2014 in Wallops Flight Facility, orbital's Antares launch vehicle failed and heavily exploded onto the launch pad area. At that time, the US transportable array of more than 200 operating stations (all equipped with microbarometers), was located on the east coast of the US and surrounded the accident. A large amount and variety of infrasound phases were observed at some stations, highlighting interesting propagation effects. The variety of recorded signals on such a dense network is unprecedented and offers the opportunity to better understand some propagation features, such as (1) the frequency content changes of stratospheric phases; (2) the dispersion of tropospheric phases propagating over thousands of kilometers within a stable and thin waveguide at fast phase speeds (350m/s) with low attenuation; (3) the non-linear effects associated with slow thermospheric phases (180m/s), especially in terms of shape, amplitude and duration. These 3 points will be addressed, and pieces of interpretations will be given thanks to the different propagation techniques: full waveform modelling (Normal Modes, finite element method), parabolic equation and ray tracing technique. Location issues of such an acoustic event based on tens of infrasound arrival times only will also be shown and discussed.

Primary author: VERGOZ, Julien (CEA/CENTRE Ile-de-France)

Presenter: VERGOZ, Julien (CEA/CENTRE Ile-de-France)

Track Classification: 4. Infrasound Modelling and Network Performance

ID: Type: **Oral**

SSW forecast evaluation using infrasound

Accurate prediction of Sudden Stratospheric Warming (SSW) events is important for the performance of numerical weather prediction due to significant stratosphere–troposphere coupling. In this study, for the first time middle atmospheric numerical weather forecasts are evaluated using infrasound. A year of near continuous infrasound from Mt. Tolbachik (Kamchatka, Russian Federation) is compared with simulations using high resolution deterministic forecasts of the European Centre for Medium-range Weather Forecasts (ECMWF). This study focuses on the period around the 2013 major SSW, and shows that while the SSW onset is better captured by the ten day forecast, the duration and recovery is better captured by the nowcast. As such, this study demonstrates the use of infrasound in the evaluation of middle atmospheric weather forecasts and therefore its potential in the assessment of tropospheric forecast skill.

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Track Classification: 4. Infrasound Modelling and Network Performance

ID: Type: **Oral**

method of decomposition of infrasonic signals from pulsed sources

The proposed method is based on the decomposition of infrasonic signals from pulsed sources. The recorded infrasonic signal is decomposed on a sequence of the acoustic pulses having the forms of U and N waves. Each U and N wave corresponds to the reflection of sound from the atmospheric inhomogeneities at different altitudes in the atmosphere. By determining the time intervals between such waves it is possible to determine the vertical gradients of the effective sound speed at different altitudes in the atmosphere. The vertical profiles of the vertical gradients of the effective sound velocity in the atmosphere by using infrasound signals recorded from different pulsed sources are obtained. The obtained data are interpreted with the theory of fine structure formation in the upper atmosphere.

Primary author: KULICHKOV, Sergey (A.M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences)

Presenter: KULICHKOV, Sergey (A.M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences)

Track Classification: 4. Infrasound Modelling and Network Performance

ID: Type: **Oral**

-Dimensional Finite-Difference Time-Domain Simulation of Explosion Infrasound in Rough Topography

We investigate the impact of rough surface topography on atmospheric infrasound propagation by means of full 3D numerical simulations. The geometry of the reflecting surface and/or structures near the acoustic source strongly influences the development of acoustic waves, thereby affecting the sound radiation patterns in the far field. The linearized Euler equations, describing acoustic overpressures in the presence of background flows, are solved by Finite-Difference Time-Domain (FDTD) method. The FDTD method has advantages to account for complex wave phenomena such as reflection, diffraction, and scattering by arbitrary objects, which may not be properly handled by acoustic rays. Parallel algorithms are implemented to distribute large workload across CPU/GPU clusters. Surface topography, sound speed variation, and wind profiles are taken into consideration for realistic atmospheric propagation. We characterize sound propagation patterns in a series of numerical simulations with different surface topographies and investigate the topographic propagation effects in combination with atmospheric sound speed and wind gradients. Finally, the result of numerical modeling is compared to the acoustic overpressures observed from chemical explosion experiments for verification. By understanding sound propagation in realistic emplacement conditions and atmospheric properties, we expect to improve acoustic source characterization substantially (e.g., yield and explosion mechanisms).

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Track Classification: 4. Infrasound Modelling and Network Performance

ID: Type: **Oral**

infrasound propagation modelling using the reflectivity method

A realistic modeling of infrasound propagation is necessary for acoustic event detection and location, and for evaluating models of the state of the atmosphere. Infrasound arrivals are typically predicted using ray-tracing although full-waveform modeling is frequently necessary. The reflectivity method generates synthetic seismograms for point sources in a layered medium. For an accidental explosion in northern Norway, we demonstrate using effective sound speed that reflectivity in a layered model of the atmosphere predicts all the observed phases at 410 km distance. Ray-tracing using the same atmospheric model fails to predict one of these arrivals which, comparing reflectivity and ray-tracing output at closer distances, is demonstrated to be a first bounce stratospheric arrival. We advocate using reflectivity in parallel with ray-tracing for providing a more complete view of the infrasound wavefield including head-waves and shadow zone arrivals.

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Track Classification: 4. Infrasound Modelling and Network Performance

ID: Type: **Oral**

study of the vertical atmospheric structure

The vertical structure of wind field in the upper stratosphere and mesosphere obtained by infrasound probing method is studied. The method is based on the effect of infrasound scattering from highly anisotropic wind velocity and temperature inhomogeneities in the atmosphere. The vertical wavenumber spectra and coherences of the retrieved vertical profiles of wind velocity fluctuations are obtained. Particularly, such profiles were retrieved from the signals recorded for different azimuths at a range of 100-120 km from volcanoes in Kamchatka. The infrasound propagation from volcanoes and surface explosions through the atmosphere with the retrieved profiles of the effective sound speed is modeled by using parabolic equation method. The obtained consistency between modeled and recorded infrasound signals at different ranges from the infrasound source shows that real-time retrieval of the fine-scale wind velocity structure allows us to better predict infrasound field and localize its source as compared to the case when such structure is not taken into account in the existing atmospheric models. The possibility of using retrieved wind velocity structure for improving the models of long-range infrasound propagation in the atmosphere is discussed

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Track Classification: 4. Infrasound Modelling and Network Performance

ID: Type: **Oral**

Statistical Framework for Estimating Atmospheric Winds using Continuous Infrasound

Infrasonic energy is known to propagate into the upper atmosphere before returning to the ground surface. A number of researchers have shown that transient infrasonic signals observed at spatially separated points can be used to estimate characteristics of the atmospheric winds. A statistical framework will be presented to demonstrate the extension of such methods to continuous infrasonic signals. Using this formulation, the inversion can be applied to a number of types of infrasonic "noise" such as microbaroms and wind farm infrasound to continuously monitor variations in the local atmospheric winds. The primary limitations of the application to such an approach are due to 1) the precision to which ground-to-ground propagation times can be identified and 2) the level of complexity allowed in the atmospheric model. The second of these concerns will be discussed in detail and compared with current atmosphere inversion methods and results.

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Track Classification: 4. Infrasound Modelling and Network Performance

ID: Type: **Oral**

: Stochastic propagation models for decision analysis

While long-range infrasound propagation modeling is a useful tool in geophysics and nuclear treaty verification, the inherent unpredictability of subgrid-scale atmosphere dynamics results in a poorly constrained propagation medium. This work reports on the project FLOWS (Fast Low Order Wave Simulation) that begun in 2013 and whose aim is to reformulate the problem in a probabilistic framework by using stochastic reduced models. Signal statistics are obtained by computing a few propagating modes over large ranges of frequencies, along with probabilistic inference to incorporate atmospheric data. Such a probabilistic model enables integrating the uncertainties associated with a hypothesized event and the atmosphere. A stochastic parameterization of gravity waves (GWs), currently in use in a general circulation model, is adapted to estimate the GW field unresolved in the large-scale atmospheric specifications. By examining how the GW field manifests statistically within the waveforms, it is shown how we can update the numerically obtained signals from the underlying probabilistic GW field. Applied in the context of the International Monitoring System (IMS), FLOWS achieves uncertainty quantification of the continuous stream of recorded signals and enables associations based on a Bayesian framework. It also predicts signals that are missed by the classical high-frequency techniques.

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Track Classification: 4. Infrasound Modelling and Network Performance

ID: Type: **Oral**

launches of carrier rockets from Baikonur cosmodrome recorded by infrasound and seismic stations of KZNET network

Starting from 1957, Baikonur cosmodrome located in Central Kazakhstan launches rockets on a regular basis. The flight traces pass over the territory of Kazakhstan where the infrasound and seismic stations of KZNET network are installed. KNDC Data Centre conducts detailed analysis of seismic and acoustic records of events of different nature round-the-clock; among them there are some associated with launch, flight, accident falls and burst of carrier rockets. The records of Kazakhstan seismic and infrasound stations were studied on availability of signals connected with accident falls of rockets for the period 1994.06-2015.06. Seismic and acoustic records from stations ABKAR, AKTO (AS59), BRVK, BVAR(AS57), IS31, KKAR, OTUK, VOS connected with large accidents of carrier rockets Dnepr (July 26, 2006), Proton (September 5, 2007 and July 2, 2013) were studied in details.

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Track Classification: 5. Analysis of Infrasound Sources and Scientific Applications of Infrasound

ID: Type: **Oral**

waves observed through measurements of the uncorrelated tropospheric noise between 0.5 and 6 Hz

The coupling between gravity waves and the turbulence-generated atmospheric noise has been studied from the beginning of 1970:ies. The uncorrelated atmospheric noise, normally considered as an obstacle when detecting weak infrasonic signals, may be, studying its envelope, used to extract gravity waves passing through the turbulent medium. Dimensions of arrays of the Swedish-Finnish Infrasound Network (SFIN) are to small (75 x 75 meters) to determine the angle of arrival and the phase velocity of detected gravity waves. However, the frequency spectrum of observed gravity waves and its temporal variations may be determined. Examples of gravity wave spectra generated by large meteoroid entries, rocket launch and major explosions are presented.

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Track Classification: 5. Analysis of Infrasound Sources and Scientific Applications of Infrasound

ID: Type: **Oral**

Waveform Inversion and Mass Flux Validation from Sakurajima Volcano, Japan

Recent advances in numerical wave propagation modeling and station coverage has permitted robust inversion of infrasound data from volcanic explosions. Complex topography and crater morphology has been shown to substantially affect the infrasound waveform, suggesting homogeneous acoustic propagation assumptions are invalid. Volume flux estimates from the infrasound waveform inversion provide an exciting tool for accurate characterization of both volcanic and non-volcanic explosions. Mass flux, arguably the most sought-after parameter during a volcanic eruption, can be determined from the volume flux if the volcanic flow is well-characterized. Thus far, infrasound-based volume and mass flux estimates have yet to be validated. In February 2015 we deployed six infrasound stations around the explosive Sakurajima Volcano, Japan for 8 days. Here we present our waveform inversion method and volume and mass flux estimates of numerous explosions using a high resolution DEM and 3-D Finite Difference Time Domain modeling. Several ground-based instruments and methods are used to independently determine the volume and mass flux of individual volcanic explosions. We compare the volume and mass fluxes estimates and discuss sources of error and future improvements. Our technique may produce realistic estimates of mass flux and plume height and extent necessary for volcanic hazard mitigation.

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Track Classification: 5. Analysis of Infrasound Sources and Scientific Applications of Infrasound

ID: Type: **Oral**

infrasound data portal

In the context of the ARISE research infrastructure project, an infrasound data portal has been developed. The portal will provide access to raw infrasound data from European stations as well as advanced data products that are useful for civil applications and the study of atmospheric structure using infrasound data. In this presentation, the current features and future developments of the portal are discussed.

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Track Classification: 5. Analysis of Infrasound Sources and Scientific Applications of Infrasound

ID: Type: **Oral**

infrasound: A new way to explore the 3D acoustic wavefield

As a part of the Source Physics Experiment (SPE) site characterization and explosive test series, we developed and deployed an airborne octocopter infrasound platform. Traditionally, infrasound data is collected with sensors and arrays that are installed on the ground. For most applications this is sufficient but can be limiting when observing non-isotropic sources, such as underground explosions, at close range. To develop and test the airborne infrasound platform we recorded data from the HK Exploration Seismo-Acoustic Hammer at the Nevada National Security Site. During early field-testing of the hammer source we found that, as the 13 metric ton mass hit the ground, a significant downward deflection of the surrounding surface imparted an observable infrasound pressure wave into the atmosphere. We compared waveforms collected at various vertical and horizontal offsets from the hammer source and found that the peak frequencies differed when observed directly above the source compared to the horizontal offsets. This work was done under award number DE-AC52-06NA25946. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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Track Classification: 5. Analysis of Infrasound Sources and Scientific Applications of Infrasound

ID: Type: **Oral**

from the October 28, 2014 Antares Rocket Detonation

On October 28, 2014 the launch of an Antares rocket from the Wallops Island Air Force Base in northern Virginia on the US eastern seaboard failed. To prevent the uncontrolled damage that could result from an uncontrolled launch the rocket was detonated. The detonation occurred at about 18:22:45 local time, producing a large explosion. Propagation conditions at the time were ideal: there was a temperature inversion and a well developed jet stream flowing up along the eastern seaboard providing a good ground duct for the near field propagation. In addition there was a well developed, eastward flowing stratospheric jet allowing the signal generated in the near field to propagate efficiently far up the east coast. Fortuitously, many of the USArray stations had been left in place providing a network of infrasound stations covering the full 180 degrees of azimuth available on the mainland. Details of the signal as it was generated in the near field and launched to the far field will be discussed.

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Track Classification: 5. Analysis of Infrasound Sources and Scientific Applications of Infrasound

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). Amplitude attenuation of MAWs from Drakensberg Mountain range is studied. Observed attenuation at two IMS infrasound stations IS35 and IS47 was compared with Raytracing technique using Bass & Sutherland, 2003 absorption model. PMCC method is used to process infrasound data. IS47 detects signal from Drakensberg Mountain almost over the year. However, in IS35 bulletin this source is observed only from December to March and between June and July. Amplitude attenuation is due to atmospheric absorption of acoustic energy along its propagation. At first approximation, amplitude decreases with range.

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Track Classification: 5. Analysis of Infrasound Sources and Scientific Applications of Infrasound

ID: Type: **Oral**

detection and cataloging of global explosive volcanism using the IMS infrasound network

Explosive volcanic eruptions are among the most powerful sources of infrasound observed on earth, with recordings routinely made at ranges of hundreds to thousands of kilometers. These eruptions can also inject large volumes of ash into heavily travelled aviation corridors, thus posing a significant societal and economic hazard. Detecting and counting the global occurrence of explosive volcanism helps with progress toward several goals in earth sciences and has direct applications in volcanic hazard mitigation. This project aims to build a quantitative catalog of global explosive volcanic activity using the International Monitoring System (IMS) infrasound network. We are developing methodologies to search systematically through IMS infrasound array detection bulletins to identify signals of volcanic origin. We combine infrasound signal association and source location using a brute-force, grid-search, cross-bearings approach. The algorithm corrects for a background prior rate of coherent infrasound signals in a global grid. When volcanic signals are identified, we extract metrics such as location, origin time, acoustic intensity, signal duration, and frequency content, compiling the results into a catalog. This work represents a step toward the goal of integrating IMS data products into global volcanic eruption early warning and notification systems.

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Track Classification: 5. Analysis of Infrasound Sources and Scientific Applications of Infrasound

ID: Type: **Oral**

Spatial Coherence Structure of Infrasonic Waves in the European Arctic from Regional Events

The spatial correlation of infrasound signals influences both infrasound array design and signal detectors. Previous atmospheric acoustic studies have identified anisotropic coherence loss across infrasound arrays, with greater loss for sensor-separations perpendicular to the direction of propagation than parallel. A recent study confirmed this anisotropy for International Monitoring System (IMS) infrasound array data. It is, however, difficult to identify the source of the coherence loss due to the differences in source-to-receiver paths. Therefore, we investigate the coherence structure of multiple signals recorded between one ground-truth source (munitions explosions in Hukkakero, Finland) and one station (the 10 element array at IS37, Norway). The source-to-receiver range is 320 km, with signals expected to be first bounce stratospheric. In agreement with previous studies we observe anisotropic coherence loss across the array. Initial results suggest coherence loss increases with decreasing celerity: lower celerities correspond to longer paths and hence greater coherence loss. The coherence loss for this range agrees well with the global study results that suggest the coherence loss depends on source-to-receiver range. The relationship between the boundary layer windspeed and coherence loss will also be investigated.

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Track Classification: 5. Analysis of Infrasound Sources and Scientific Applications of Infrasound

ID: Type: **Oral**

waves from marine storms –"voice of sea"

Some data on a high-frequency infrasound recorded within a range of 2–16 Hz ("voice of the sea") in the water area of the Black Sea are given. Different parameters of the recorded infrasonic signal - the direction and phase velocity of arriving infrasonic waves, spectral composition, and coherence - have been studied. Wind and wave conditions in the water area of the Black Sea were studied in detail. The collision of two atmospheric vortices was observed a few hours before the first arrivals of infrasonic waves, and the collision of differently directed sea waves was observed during the recording of infrasound. The direction of the arrivals of infrasonic waves coincided with the direction between the zone of collision of sea waves and the point of infrasound recording. The assumption was made that, in order to explain the observed infrasonic waves, it is necessary to use the mechanism responsible for the emission of infrasound into the atmosphere by standing surface waves formed due to the nonlinear interaction of surface waves propagating in opposite directions and to take into account the frequency-filtering properties of both wind-velocity and temperature stratifications of the atmosphere itself along the path of infrasound propagation.

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Track Classification: 5. Analysis of Infrasound Sources and Scientific Applications of Infrasound

ID: Type: **Oral**

Characterization from Repeating Seismoacoustic Events: Exploiting the Synergy of Seismic and Infrasound Data

Remote event detection and location using infrasound requires high quality temporal and spatial atmospheric models. Large industrial blasts and military explosions are tightly constrained in time and space using seismic data and can generate infrasound recorded both regionally and globally. The most useful seismo-acoustic sources are repeating sources with relatively frequent explosions, sampling the infrasonic wavefield over many time-scales. An extensive database of explosions from many sites in Fennoscandia and northwest Russia has been compiled, dating back to the late 1980s. Each event is associated confidently with a known source, with an accurately determined origin time, usually by applying waveform correlation or similar techniques to the characteristic seismic signals generated. For selected repeating sources and infrasound arrays, we have assessed the variability of infrasonic observation: including the documentation of lack of observed infrasound. These observations provide empirical celerity probability distributions. Such empirical distributions have been demonstrated in numerous recent studies to provide infrasonic event location estimates with significantly improved uncertainty estimates. Tropospheric, stratospheric and thermospheric returns have been observed, even at distances below 200 km. This information is now providing essential input data for studies of the middle and upper atmosphere.

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Track Classification: 5. Analysis of Infrasound Sources and Scientific Applications of Infrasound

ID: Type: **Oral**

effort to utilize the infrasound observation network data for reducing damage from convective storms and lightning

In order to understand regional infrasound sources and improve the accuracy of the discrimination for the nuclear test, the development of the infrasound monitoring system with a low-cost and compact size has been started and the portable infrasound observation kit by using the nano-resolution digital quarts resonator sensor (Paroscientific, Inc., USA) was developed in 2011. Until now, in order to limit damage caused when a disaster strikes associated with explosive volcanos, tsunamis, snow avalanches, convective storms and lightning, several portable kits have been deployed in array configuration in Japan. In the summer and early fall every year, many thunderstorms occur and pass near the infrasound station and many interesting infrasound signals associated with these thunderstorms are detected by the infrasound observation network. In this presentation, we would demonstrate the signal generation mechanism by comparing the information obtained from X band multiparameter radar with the characteristics of these infrasound signals.

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Track Classification: 5. Analysis of Infrasound Sources and Scientific Applications of Infrasound