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Tuesday 12 June, 2018

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*The last presentation given by V.E. Ostashev is jointly held with the Summer School on Atmospheric sound propagation. It will be hosted at Valpré conference center close to École Centrale de Lyon in Écully. Transportation to Valpré conference center will be provided for participants of LRSP who are interested.

Abstracts:

Outdoor acoustic Green's function extraction

Tuesday 12 June: 09:00 - 09:25

M.F. Denis, S.L. Collier, D.A. Ligon, J.M. Noble, W.C. Kirkpatrick Alberts, II, L. Sim, C.G. Reiff and D.D. James

U.S. Army Research Laboratory, Adelphi, Maryland 20783-1138, USA

sandra.l.collier4.civ@mail.mil

In this work, the utility of Green's function extraction methods to characterize an outdoor environment is investigated. Open field and forest area experiments were conducted in Southern Maryland. An analysis of the effects of source distribution to the accuracy of the retrieved Green's function is presented. Of particular interest are the following variables: (1) source radius; (2) source angle distribution; (3) source density distribution. The remote sensing applications of the retrieved Green's function for localization and atmospheric sounding are analyzed with beamforming and acoustic tomography, respectively.

An experimental study on the atmospheric-driven variability of impulse sounds

Tuesday 12 June: 09:25 - 09:50

S. Cheinet[1], M. Cosnefroy[1], S.L. Collier[2], A. Dagallier[1], V.E. Ostashev[3], W. Rickert[4], T. Wessling[4] and D.K. Wilson[3]

[1] French-German Research Institute of Saint-Louis, 68301 Saint-Louis, France
[2] U.S. Army Research Laboratory, Adelphi, Maryland 20783-1138, USA
[3] U.S. Army Engineer Research and Development Center, CRREL, Hanover, New Hampshire 03755, USA
[4] Wehrtechnische Dienststelle 91, Schiessplatz, D49716 Meppen, Germany

sylvain.cheinet@isl.eu

Propagating impulse sounds are sensitive to the varying near-surface atmosphere. This study reports on an experimental assessment of this sensitivity under well-controlled outdoor conditions. The experiment, conducted over a flat terrain, features 14 synchronous acoustic sensors at ranges up to 450 m from reproducible, transient sources. It scans over upwind, crosswind and downwind propagations, and also documents the temporal and spatial coherences of the acoustic field. Concurrent atmospheric measurements document the near-surface, essentially wind-driven atmosphere, and include turbulence monitoring. The analysis reveals how the environmental propagation processes combine to form the large variety of recorded signatures. The deterministic versus stochastic variations of the signatures are distinguished, and both are shown to affect the time of arrival (wander) and the shape (spread) of the pulses.

Long range sound propagation in a refractive atmosphere: time-domain simulations versus measurements

Tuesday 12 June: 09:50 - 10:15

M. Cosnefroy[1], S. Cheinet[1], L. Ehrhardt[1], A. Dagallier[1], D. Dragna[2] and D. Juvé[2]

[1] French-German Research Institute of Saint-Louis, 68301 Saint-Louis, France

[2] École Centrale de Lyon, LMFA UMR CNRS 5509, F-69134 Écully, France

matthias.cosnefroy@isl.eu

Characteristics of impulse sounds propagating close to the ground strongly depend on the atmospheric and ground properties in terms of amplitude, shape, and time of arrival. Whereas full-wave time-domain 3D numerical modeling is valuable to decipher the interactions between the refractive, scattering and ground effects, it remains challenging as to the computational resources needed for long-range and/or broadband applications. This requires trading off the computational cost against robustness and physical accuracy (e.g. by using coarse meshes for faster simulations at the expense of a low spectral resolution, or considering larger domains to decrease the edge effects). A careful validation through comparison to experimental data in a well-controlled environment is necessary to ensure reliable numerical results and subsequent physical interpretations. An original 3D parallel Finite-Difference Time-Domain solver is presented. The model is assessed against outdoor measurements up to 450 meters under different weather conditions from estimations of the mean vertical atmospheric profiles and of the ground impedance. An excellent agreement is obtained in most cases, which allows to further discuss the sensitivity of impulses to the ground properties downwind and upwind.

Measured sound level difference in relation to the effective sound speed gradient

Tuesday 12 June: 11:00 - 11:25

E. Mursch-Radlgruber[1], D. Hohenwarter[2] and C. Kirisits[3]

[1] University of Natural Resources and Life Sciences, Institute of Meteorology (BOKU-Met), Vienna, Austria

[2] TGM - Institute of Technology, Department for Research and Testing, Vienna, Austria

[3] Kirisits - Chartered Engineering Consultants, Pinkafeld, Austria

erich.mursch-radlgruber@boku.ac.at

The effective sound speed gradient is used to classify the meteorological sound propagation conditions during sound measurements at a distance $\geq$ 100 m from the sound source. Four measurement series were performed along motorways and railway tracks. The sound level difference was determined between a reference point close to the passing vehicles and at distance of 100 m to 500 m together with the assessment of meteorological parameters. These sound level differences correlate with the effective sound speed gradient calculated from the measured temperature and vector wind speed gradient. The variations follow the day/night cycle as a result of the reversing air temperature gradient, radiation balance and up- versus downwind. The function of the sound level difference based on the gradients show a steeper linear regression line for larger distances demonstrating the increasing influence of the meteorological effects. The sound level difference in relation to the effective sound speed gradient are very similar to the similarity relationships used in Monin Obukhov theory. It seem that under stable meteorological conditions a linear relationship is present and another linear behaviour is given during unstable situations. Experimental results will be shown and discussed.

Spectral broadening of acoustic waves by a convected layer of synthetic turbulence

Tuesday 12 June: 11:25 - 11:50

V. Clair[1,2] and G. Gabard[1,3]

[1] University of Southampton, Institute of Sound and Vibration Research, Southampton SO17 1BJ, UK
[2] École Centrale de Lyon, LMFA UMR CNRS 5509, F-69134 Écully, France
[3] Le Mans Université, LAUM UMR CNRS 6613, F-72085 Le Mans, France

vincent.clair@ec-lyon.fr

The scattering of acoustic waves propagating through a time-evolving inhomogeneous medium gives rise to a phenomenon known as spectral broadening. For a harmonic source scattered by a layer of convected turbulence, the acoustic spectra typically observed show a reduction of the peak amplitude at the source frequency and the appearance of sidebands surrounding the peak. The reduction of the peak amplitude, as well as the shape and levels of the sidebands, are evolving with the parameters of the source and the flow. In the present work, spectral broadening is studied numerically for a two-dimensional configuration consisting in a harmonic point source propagating through a layer of turbulence with constant thickness and convected by a uniform mean flow. The Euler equations, linearized around an unsteady base flow formed by the sum of the convection flow and synthetic turbulent fluctuations, are solved in the time domain using a finite difference code. The turbulent layer is synthesized using a stochastic method based on the filtering of white noise to impose prescribed statistical properties to the velocity field. The results are presented for several source frequencies and convection velocities. The trends deduced from these results are in agreement with previous observations found in the literature.

A wide-angle parabolic equation method for handling discontinuities in vertical profiles

Tuesday 12 June: 11:50 - 12:15

M.E. Swearingen, M.J. White and M.H. McKenna

U.S. Army Engineer Research and Development Center, CERL,
Champaign, Illinois 61826, USA

michelle.e.swearingen@usace.army.mil

Low-frequency (< 50 Hz) acoustic propagation for long ranges (10-100 km) is critical for low-logistical footprint, non-line of sight, persistent surveillance of critical infrastructure and associated human usage over large domain areas. A deep understanding of the myriad of ways that the natural environment influences the signal is critical for accurate interpretation of received signals at monitoring stations. Taking cues from the underwater acoustics community, a flexible, wide-angle, finite-element PE model has been developed. This model handles discontinuities as well as gradual variations in density and wavenumber, allowing abrupt changes to the vertical density and wavenumber profiles. An overview of the mathematical development, comparisons to benchmark cases, preliminary comparisons to measurements, and an exploration of the strengths and limitations of this method are presented.

This work was funded by the Assistant Secretary of the Army (Acquisition, Logistics, and Technology) [ASA(ALT)] with portions funded under 62784/T40/24.

Sound propagation from a wind turbine in complex terrain

Tuesday 12 June: 14:00 - 14:25

A. Schady

German Aerospace Center (DLR), Institute of Atmospheric Physics,
Wessling-Oberpfaffenhofen, Germany

arthur.schady@dlr.de

Prediction of possible disturbances caused by wind turbine (WT) noise is getting increasingly important because of the growing number of installations, what in consequence is not only subject to reduced distance to dwellings but also the meteorological conditions and terrain characteristics. During a 40-day field experiment in Perdigão, Portugal [Fernando H.F. et.al. 2018], a dataset of unique detail was created. The topography of the site resembles a text book case of a two-dimensional (2-d) valley between parallel ridges. The broad sound spectrum and the meteorological conditions during propagation time were regarded explicitly. Due to different source-receiver distances and angles we were able to deduce background noise and directivity of sound emission. The challenge in describing the sound propagation is to regard both, the spatial distribution of sound impact as well as the temporal variation at any fixed point in the surrounding of a wind turbine. Depending on whether the sound propagation or the spatial distribution of sound immission is in the focus of investigation the measurement strategy differs. The measurements were performed simultaneously with five microphones at different locations to assess the spatial effects on the sound propagation. By measuring sound immission at fixed locations during many days, we monitored the variations caused by weather on both sound generation and propagation. The source-receptor configuration remained constant, while the environmental conditions changed. The identification of the sound signal from the wind turbine and its distinction from extraneous sound, e.g. from leafs, animals, people, wind etc. is not trivial. A timewise shutdown of WT facilitated this distinction. The results of our measurements reveal a clear signal from the wind turbine at least in a few 1/3-octave bands (e.g. 80 Hz) and show a variance of up to 30 dB in this band between times, when the turbine was operating and shut down. Additionally other influences affecting the sound propagation like the low level jet and situations with a recirculation in the valley are shown in this presentation.

References:

Fernando H.F. et al. (2018): "The Perdigão: Peering into Microscale Details of Mountain Winds" submitted to Bulletin of the American Meteorological Society

A new experimental database for wind turbine noise propagation in an outdoor inhomogenous medium

Tuesday 12 June: 14:25 - 14:50

B. Kayser[1], B. Gauvreau[1], D. Ecotière[2] and C. Le Bourdat[3]

[1] IFSTTAR - Cerema, UMRAE, Bouguenais, France
[2] Cerema - IFSTTAR, UMRAE, Strasbourg, France
[3] Engie Green, Nantes, France

bill.kayser@ifsttar.fr

Wind turbine noise is directly concerned by physical phenomena related to long range sound propagation, i.e. ground effects (roughness, topography, impedance), and meteo effects (mean refraction, intermittency fluctuations, small-scale turbulence scattering). Quantifying the overall variability and uncertainties associated with the emission-propagation-reception chain thus appears essential for controlling the acoustic impacts of wind turbines in an inhomogeneous outdoor medium. In this context, a large-scale experimental campaign was carried out in 2017 to study the emission and propagation of wind turbine noise as a function of various influent parameters (wind and temperature fields, blade pitch, ground properties, etc.). For this purpose, more than 20 sound measurement points (sound pressure level meters, audio recordings) were carried out during one week (7 days, 24/24h), including "ON/OFF" phases of the wind turbines, both in the near field (characterisation of the sound power of the machines) and in the far field (up to 1.5 km) on a frequency range including infrasound (down to 1 Hz). Simultaneously, micrometeorological monitoring were carried out using several types of devices (Lidar, 3D sonic anemometers and high meteorological mast) at different locations on the site. These surveys were supplemented by in situ acoustic impedance measurements at different locations of the surrounding types of grounds. The aim of this communication is to present the measurement campaign and the associated database, including post-processing and first analyses for future applications.

An overview of scattered signal distributions and extensions to include parametric uncertainties

Tuesday 12 June: 14:50 - 15:15

D.K. Wilson[1], C.R. Hart[1], C.L. Pettit[2], D.J. Breton[1], E.T. Nykaza[3] and V.E. Ostashev[1]

[1] U.S. Army Engineer Research and Development Center, CRREL,
Hanover, New Hampshire 03755, USA
[2] U.S. Naval Academy, Aerospace Engineering Department,
Annapolis, Maryland, USA
[3] U.S. Army Engineer Research and Development Center, CERL,
Champaign, Illinois 61826, USA

d.keith.wilson@erdc.dren.mil

A variety of probability distributions, with varying analytical advantages and ranges of physical applicability, have been proposed for random signal variations caused by wave scattering. The scattering may be caused by many terrestrial phenomena, including atmospheric variations such as turbulence, forests, buildings, and surface-elevation variations. We describe here a general modeling approach based on compound probability density functions (pdfs), in which a basic pdf, attributable to the underlying scattering process, has uncertain parameters or is modulated by variability in the environment, as described by a second pdf. We also discuss analogies between the compound pdf formulation and Bayes' theorem, according to which the pdf for the scattering process may be viewed as a Bayesian likelihood function and the modulating pdf as a Bayesian prior. The use of a Bayesian conjugate prior leads to particularly convenient analytical solutions for the scattered signal pdf. Furthermore, the parameters of the modulating process (hyperparameters) can be refined by simple sequential updating as additional transmission data become available. We describe here several practical examples, including strong scattering modulated by an inverse gamma pdf for the mean power, and weak scattering (Rytov approximation) modulated by a normal pdf for the log-mean of the signal. An application to updating mean sound transmission loss estimates, based on repeated signal observations, is discussed.

Application of 3D multiple scattering theories to forest acoustics

Tuesday 12 June: 16:00 - 16:25

V.E. Ostashev[1], D.K. Wilson[1], M.B. Muhlestein[1], and K. Attenborough[2]

[1] U.S. Army Engineer Research and Development Center, CRREL,
Hanover, New Hampshire 03755, USA

[2] Open University, Milton Keynes, MK7 6AA, UK

vladimir.ostashev@colorado.edu

For predicting noise reduction by a stand of trees or for localizing sound sources, it is important to make sufficiently accurate predictions of sound propagation through a forest. Currently, however there are no satisfactory prediction methods. This presentation overviews recently suggested approaches for forest acoustics based on 3D multiple scattering theories. The mean sound field, which approximates the mean intensity for relatively short propagation ranges, is calculated with use of the effective wave number due to sound scattering by trunks, large branches, and the canopy. Trunks and branches are modeled as vertical and slanted finite cylinders, respectively, and the canopy is approximated by diffuse scatterers. The radiative transfer equation for forest acoustics is formulated. Using this equation, the mean intensities transmitted and backscattered from a stand of trees are calculated and analyzed. Pulse propagation in a forest is analyzed based on a modified Born approximation and corresponding predictions are compared with experimental data. Also it is shown that there is a correspondence between sound propagation in a turbulent atmosphere and a forest. This correspondence is used to predict the influence of scattering by forest elements on the coherence between the direct and ground reflected waves and predictions are compared with experimental data.

Adjoint of an approximate wave operator applied to the acoustic propagation in an arbitrary mean flow

Tuesday 12 June: 16:25 - 16:50

E. Spieser[1,2] and C. Bailly[1]

[1] École Centrale de Lyon, LMFA UMR CNRS 5509, F-69134 Écully, France

[2] Safran Aircraft Engines, Aerodynamics and Acoustics Department, Moissy Cramayel, France

etienne.spieser@ec-lyon.fr

In this study, we show how adjoint theory can be used to solve sound propagation in the presence of convection and refraction effects, as encountered in aeronautics for jet noise and the prediction of installation effects. It is well established that the use of an exact wave operator obtained by linearization of the Euler equations around a shear mean flow leads to include possible instability waves in the solution, due to the acoustic-vortical mode conversion. Based on the adjoint theory, especially on the stability property of self-adjoined systems, a stable formulation is proposed for the acoustic propagation. A new second-order wave operator written for the fluctuating velocity vector is derived under the assumption of a parallel mean flow, and some properties are highlighted. Finally, the capability of various formulations - including linearized Euler equations, Lilley's equation, the convected Helmholtz equation and the proposed wave operator - to predict mean flow effects of sound propagation are numerically illustrated.

Propagation effects on acoustic particle velocity sensing

Tuesday 12 June: 16:50 - 17:15

S.L. Collier[1], M.F. Denis[1], D.A. Ligon[1], L.I. Solomon[1], J.M. Noble[1], W.C. Kirkpatrick Alberts, II[1], L.K. Sim[1], C.G. Reiff[1], D.D. James[1] and M.M. Erikson[2]

[1] U.S. Army Research Laboratory, Adelphi, Maryland 20783-1138, USA

[2] U.S. Military Academy, West Point, New York, USA

sandra.l.collier4.civ@mail.mil

Acoustic vector sensing has been established in the underwater community, and is gaining interest in the atmospheric community as technologies continue to improve. The effects of atmospheric turbulence on acoustic pressure-sensor arrays has been well studied and documented. Two-dimensional acoustic particle velocity and acoustic pressure, concurrent with atmospheric data, were collected during a series of field tests. Here, the effects of atmospheric turbulence on the acoustic particle velocity are examined for both narrow-band and wide-band sources. The statistical distributions of the acoustic particle velocity and pressure fields are analyzed and applications to signal processing with particle velocity sensors are considered.

Modeling of nonlinear N-wave propagation in a turbulent layer: pressure field distortions and statistics

Tuesday 12 June: 17:15 - 17:40

P.V. Yuldashev[1], M.M. Karzova[1], S. Ollivier[2], V.A. Khokhlova[1] and P. Blanc-Benon[2]

[1] M.V. Lomonosov Moscow State University, Physics Faculty, Moscow, 119991, Russia

[2] École Centrale de Lyon, LMFA UMR CNRS 5509, F-69134 Écully, France

petr@acs366.phys.msu.ru

Numerical experiments on N-waves propagation through a turbulent layer were performed based on the 2D parabolic KZK-type equation. Acoustic pulse wavelength and spatial scales of the turbulence with a modified von Kármán spectrum corresponded to laboratory scale experiments performed earlier at École Centrale de Lyon. Similar waveform distortions were observed in numerical and laboratory experiments. Statistics of peak overpressure and shock front steepness were analyzed for linear and nonlinear propagation cases. Statistical data included cumulative probabilities to observe waveforms with increased amplitude and shock front steepness in comparison to nominal levels. In the case of linear propagation, strong caustics with high pressure level were formed at some propagation distance, but no increase of shock front steepness was observed. A propagation distance scaling law for statistical data curves was proposed to account for dependence of the distance for strong caustics formation on the turbulence intensity. Simulations with nonlinear effects demonstrated that nonlinear steepening for N-waves with initial amplitudes of 50-100 Pa was sufficient to counteract the smearing effect introduced by the turbulence.

Work was supported by RSF-17-72-10277 and by the Labex CeLyA of Université de Lyon, operated by the French National Research Agency (ANR-10-LABX-0060/ ANR-11-IDEX-0007).

Outdoor blast wave simulation in real environment

Wednesday 13 June: 09:00 - 09:25

O. Gainville, N. Lardjane and M. Nguyen-Dinh

CEA, DAM, DIF, F-91297 Arpajon, France

olaf.gainville@cea.fr

Outdoor blast wave propagation is affected by numerous physical parameters such as the source energy, the topography, the ground nature, or the atmospheric conditions. Part of these effects are deterministic and well explained using numerical simulation. Direct high performance computing method solving Euler equations is used for few meteorological conditions and to build reference solutions. A one-way coupled Euler-parabolic equation method is used to study the propagation at long range. Both direct and coupled methods take into account topography and atmospheric conditions. We show that, compared to the full Euler simulations, the coupling procedure provides accurate results at a reduced computational cost for blast wave propagation in the vicinity of a pyrotechnic site. The quality of the simulated signal is also improved in comparison with results obtained with classical parabolic using analytical starter. Statistical comparisons between simulations and measurements are also performed for numerous blast wave records of 500 kg ground explosions.

Variation of impulsive sound events on and around shooting ranges

Wednesday 13 June: 09:25 - 09:50

F. van der Eerden, P. Wessels and F. van den Berg

TNO Acoustics & Sonar Department, The Hague, The Netherlands

frits.vandereerden@tno.nl

High-energy impulsive sound events on and around a shooting range are considered. The objective is the investigation of several aspect of a management system for training exercises and environmental impact. The initial design and test of a monitoring system that automatically detects and localizes impulsive sound events is presented. It combines sound measurements and a sound propagation model. The locations of these events are obtained by combining detections from multiple measurement units. With the sound propagation model the source levels at the range as well as the sound immission levels at residential areas can be determined. When applying model results it is important to know the impact of missing or limited knowledge of environmental input data, such as meteorological and ground input data, on the accuracy of the sound propagation predictions. The main sources of environmental uncertainty are presented and their impact is quantified. This is done via a sensitivity analysis using a Green's function parabolic equation method. Finally, several aspects of a sound management system are indicated and discussed.

Acoustic localization of artillery shots

Wednesday 13 June: 09:50 - 10:15

A. Dagallier[1], S. Cheinet[1], M. Cosnefroy[1], D. Juvé[2] and P. Wey[1]

[1] French-German Research Institute of Saint-Louis, 68301 Saint-Louis, France
[2] École Centrale de Lyon, LMFA UMR CNRS 5509, F-69134 Écully, France

adrien.dagallier@isl.eu

In battlefield acoustic applications, synchronous acoustic sensors are used to localize the impact point or the source position of artillery shots. The sensors record a complex combination of the various sound signals generated by the weapon, by the projectile (supersonic) motion, by the final impact, as well as the possible reflexions. For localization purposes, one has to identify and process these various contributions, taking the sound propagation effects into account (atmospheric winds, temperature gradients, ground type, topography ...). In practice though, distinguishing and interpreting these various contributions turns out to be a challenge. In this talk, a model is presented to build a database relating projectiles' trajectories to the times of arrival (TOAs) of the sound waves at the sensors. The model combines two numerical techniques (1) ballistic calculations performed with the BALCO software, and (2) sound propagation simulations, which account for complex propagation effects. The Time-Matching technique, recently proposed by ISL, is used to find the TOAs in the database that best match those of the measured signals and thus recover the source and/or impact position. On-going developments demonstrate the potential of processing the projectile's wave in order to make the detection and localization more robust.

Irregular reflection of spark-generated N-waves from a rigid surface: optical measurements in air and numerical modeling

Wednesday 13 June: 11:00 - 11:25

M.M. Karzova[1], T. Lechat[2], D. Dragna[2], S. Ollivier[2], P.V. Yuldashev[1], V.A. Khokhlova[1] and P. Blanc-Benon[2]

[1] M.V. Lomonosov Moscow State University, Physics Faculty, Moscow, 119991, Russia

[2] École Centrale de Lyon, LMFA UMR CNRS 5509, F-69134 Écully, France

masha@acs366.phys.msu.ru

In this study, irregular reflection of weak acoustic shock waves is investigated both experimentally and numerically for spark-generated spherically divergent N-waves reflecting from a plane rigid surface in air. Two optical methods are used in the measurements: a Mach-Zehnder interferometer for reconstructing the pressure waveforms and a Schlieren system for visualizing the shock front geometry. In simulations, axisymmetric Euler equations are solved for an acoustic source introduced as a Gaussian-envelope energy injection and a rigid wall as a boundary condition. Waveforms obtained in simulations are in a good agreement with those measured by the interferometer. The Mach stem formation is observed close to the surface resulting from the collision of the incident and reflected front shocks of the N-wave and further away from the surface where the reflected front shock interacts with the incident rear shock. It is shown that irregular reflection occurs in a dynamic way and the length of the Mach stem increases following a parabolic law while the N-wave propagates along the surface.

Work supported by RSF-17-72-10277 and the Labex CeLyA of Université de Lyon, operated by the French National Research Agency (ANR-10-LABX-0060/ ANR-11-IDEX-0007).

The infrasound signal generated by the October 2014 Wallops Island Antares rocket failure

Wednesday 13 June: 11:25 - 11:50

R. Waxler and C. Hetzer

NCPA, University of Mississippi, Mississippi, USA

rwax@olemiss.edu

On the evening of October 28, 2014 an unmanned rocket was exploded at the Wallops Island launch site in Virginia shortly after takeoff due to system failure. As a result of the US Transportable Array (TA) project, there is a fairly dense network of infrasound sensors covering the Eastern United States. The atmospheric conditions at the time provided efficient propagation up the east coast of the United States. Further, the combination of temperature inversion, low altitude winds and stratospheric winds produced an interesting interaction between the near-ground duct and the stratospheric duct. The near ground duct conditioned the near-field blast wave resulting in a chirp which then propagated to the far field in the stratospheric duct. The signals detected on the TA will be shown, and the signal propagation discussed.

Acoustic- gravity waves observed during strong atmospheric storms in Moscow region

Wednesday 13 June: 11:50 - 12:15

I. Chunchuzov, S. Kulichkov, O. Popov and V. Perepelkin

Obukhov Institute of Atmospheric Physics, 119017 Moscow, Russia

igor.chunchuzov@gmail.com

The results of study of acoustic-gravity waves (AGWs) from atmospheric storms by a network of microbarometers near Moscow are presented. The temporal changes in the characteristics (such as the direction of propagation and phase velocity) of internal gravity waves (frequencies 0.001-0.003 Hz) and infrasound (0.01-0.1 Hz) generated prior and during a passage of the atmospheric storm through the network are analyzed. The differences in the characteristics of AGWs from the warm and cold fronts associated with their differences in the structure and inclination of frontal surfaces with respect to the ground are found. The possible generation mechanisms for the observed AGWs and their usage as precursors of strong atmospheric storms are discussed.

Modeling the seismo-acoustic events of DPRK's underground nuclear tests

Wednesday 13 June: 12:15 - 12:40

G. Averbuch[1,2], J.D. Assink[2], P.S.M. Smets[1,2] and L.G. Evers[1,2]

[1] Department of Geoscience and Engineering, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, the Netherlands

[2] R&D Department of Seismology and Acoustics, Royal Netherlands Meteorological Institute, De Bilt, the Netherlands.

gil.averbuch@gmail.com

In this work, seismo-acoustic modeling of DPRK's underground nuclear tests will be presented. The Fast Field Program (FFP) is used to model seismo-acoustic coupling between the solid Earth and the atmosphere under the variation of source depth and atmospheric conditions. There will be a focus on the February 2013 and January 2016 DPRK events. The results show the important role of evanescent coupling between the Earth and the atmosphere and the ability of such emitted energy to get trapped in the at- mospheric waveguides. The energy emitted to the atmosphere as a function of vertical propagation angle depends on the source's frequency and depth. As the source depth increases, less energy will be trapped in the tropospheric waveguide compared to the stratospheric waveguide. Although ECMWF atmospheric conditions suggest that the tropospheric duct towards the CTBTO infrasound array I45RU (Russian Federation) was stronger in January 2016, the shallower source in 2013 lead to enhanced tro- pospheric propagation. Moreover, the stratospheric duct was more efficient compared to January 2016. This allowed for more energy to arrive at I45RU. The simulated transmission loss values at I45RU and estimated source depth are in agreement with independent observations.

A generalized polynomial chaos-based approach of infrasound propagation

Wednesday 13 June: 14:00 - 14:25

A. Goupy[1,2], D. Lucor[3] and C. Millet[1,2]
[1] Université Paris-Saclay, ENS Cachan, CMLA UMR CNRS 8536, 94235 Cachan, France
[2] CEA, DAM, DIF, F-91297 Arpajon, France
[3] LIMSI-CNRS, F-91403 Orsay Cedex, France
alexandre.goupy@cmla.ens-cachan.fr

One main aspect of uncertainty quantification that is studied in infrasound research community is the propagation of atmospheric uncertainty, which is due to the random nature of small-scale flows. A simple approach to this problem is to use Monte Carlo (MC) based techniques, which involve a large random sample of atmospheric specifications from a given distribution. However, the proper numerical methods used to propagate sound are often too costly in terms of computational memory/time due to the large number of simulations required. Further, high dimensionality of the model severely limits the ability to compute the acoustic random field. An alternative approach addressed in this study, is to use a generalized Chaos Polynomial approximation (gPC). Used in combination with a normal-mode technique, the gPC proceeds by identifying a truncated spectral expansion of the eigenpairs of the propagation operator so as to retain the essential stochastic character of the wave equation input-output map. The efficiency of this approach is demonstrated by considering the acoustic propagation problem within a stochastic planetary boundary layer. An excellent agreement between the gPC and MC signals statistical properties is observed. This offers computational promise for the training of machine-learning models.

Towards the use of infrasound observations for improving weather forecasts

Wednesday 13 June: 14:25 - 14:50

P. Vanderbecken[1], C. Millet[1,2] and J.F. Mahfouf[3]
[1] CEA, DAM, DIF, F-91297 Arpajon, France
[2] Université Paris-Saclay, ENS Cachan, CMLA UMR CNRS 8536, 94235 Cachan, France
[3] Météo-France, CNRM, F-31000 Toulouse, France
vanderbecken.pierre@gmail.com

During the last decade significant efforts have been devoted to the determination of the role played by the atmosphere in infrasound propagation using various numerical methods to solve the wave equation. The atmospheric state is provided by a deterministic estimate obtained from a combination of Numerical Weather Prediction (NWP) models and climate reanalysis data. Presently it seems that the main part of infrasound modelling uncertainty comes from the knowledge of the atmospheric state. The main objective of this work is to examine further the relationship between the numerically obtained waveforms and the most important sources of uncertainties present in NWP models. For this purpose, ensemble analyses and forecasts from the global NWP model ARPEGE developed by the French Meteorological Office Météo-France are used in combination of ray tracing techniques and modal expansion methods for infrasound propagation. Following a number of volcanic eruption events observed at infrasound station IS48, in Tunisia, it is found that correlations exist between the signal characteristics and the statistical properties of forecasts. In addition, our results show that the use of a Bayesian approach provides posterior distributions of wind and temperature profiles directly from the ensemble statistics.

Inter-comparison of numerical models for propagation of infrasounds

Wednesday 13 June: 14:50 - 15:15

L. Robert[1], R. Marchiano[1], O. Gainville[2], C. Millet[2], L. Aubry[2], J.P. Braeuning[2], D. Dragna[3] and C. Bailly[3]

[1] Sorbonne Université/UPMC : Institut d'Alembert, Sorbonne Université, CNRS, Paris, France
[2] CEA, DAM, DIF, F-91297 Arpajon, France
[3] École Centrale de Lyon, LMFA UMR CNRS 5509, F-69134 Écully, France

loic.robert@dalembert.upmc.fr

Numerical simulation is an important tool to study the long range propagation of infrasounds through the atmosphere. Many approaches have been developed with varying degrees of approximation in their physical model and their numerical implementation, inducing a wide range of computation times and memory footprints. Facing this important variety of available models, the question of inter-comparison protocols has risen to ensure the robustness and reliability of the results. This study consists in the systematic comparison of three different models from the numerical platform of LETMA (Laboratoire Études et Modélisation Acoustiques, Laboratory of studies and modelling in acoustics): a ray tracing model, a one-way method and a direct numerical simulation approach. Equivalent formulations of the same initial source are derived for each model to enable comparison, and are validated in the case of a homogeneous atmosphere. Propagation properties, such as directivity and attenuation, are compared between the analytical solution and the three models. Then, their response for different atmospheric heterogeneous conditions, from idealized cases to more realistic ones, are analyzed and discussed.

A study of tropospheric ducting of infrasonic propagation from the Niagara Falls

Wednesday 13 June: 15:15 - 15:40

M. Willis, R. Waxler and C. Hetzer

NCPA, University of Mississippi, Mississippi, USA

rwax@olemiss.edu

The U.S. Transportable Array is a large deployment of infrasound and seismic sensor pairs across the United States. The location of existing sites allows for the study of infrasonic signals emanating from the Niagara Falls. Sites were identified near the Niagara Falls and infrasonic arrivals were found consistently throughout the year. Atmospheric profiles were obtained for the region around the Niagara Falls. These profiles were used to generate theoretical infrasound propagation models to find locations of expected arrivals from the falls. To verify Niagara Falls as the source, a back azimuth must be calculated. However, each Transportable Array site consists of a single Infrasound sensor and a 3-axis seismometer. The challenge of estimating a back azimuth from Infrasonic excitation is discussed.

Overview of acoustic tomography of the atmosphere

Wednesday 13 June: 16:30 - 18:00

V.E. Ostashev, S.N. Vecherin and D.K. Wilson

U.S. Army Engineer Research and Development Center, CRREL,
Hanover, New Hampshire 03755, USA

vladimir.ostashev@colorado.edu

Acoustic tomography of the atmosphere is similar to that in medicine where ultrasound or x-rays probe an organ of a human body resulting in an "image" of that organ. In the case of acoustic tomography of the atmosphere, acoustic pulses are used to measure the travel times of sound propagation between different pairs of speakers and microphones, which are arranged so as to create propagation paths through the region to be sampled. Then, the temperature and wind velocity fields inside the tomographic region are reconstructed by inverting the travel times. This presentation overviews general principles and concepts of tomography, a historic perspective of acoustic tomography of the atmosphere, and tomography arrays which have been used in the past. A forward problem in acoustic tomography of the atmosphere is formulated. Inverse algorithms for reconstruction of the temperature and wind velocity fields from the travel times are reviewed. The instrumentation and principle of operation of a tomography array at the Boulder Atmospheric Observatory (BAO) are explained. The array enabled horizontal-slice tomography at a height of 8 m above the ground, in an 80 m $\times$ 80 m region. Results in numerical simulations of the BAO tomography array and reconstruction of turbulence fields in tomography experiments are presented. Acoustic tomography can also be performed at other spatial scales, ranging from a size of an ultrasonic anemometer/thermometer to the height of the atmospheric boundary layer. Future developments in acoustic tomography of the atmosphere are discussed.