U32B-03 1420h INVITED

Implications from Meteoric and Volcanic Infrasound Measured in the Netherlands

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Infrasound observations started in the Netherlands in 1986. Since then, several array configurations and instruments have been developed, tested and made operational. Currently, three infrasound arrays are continuously measuring infrasound with in-house developed microbarometers. The array apertures vary from 30 to 1500 meters and the number of instruments from 6 to 16 microbarometers. The inter-array distance ranges from 50 up to 150 km. This dense network of infrasound arrays is used to distinguish between earthquakes and sources in the atmosphere. Sonic booms, for example, can be experienced in the same manner as small (gas induced) earthquakes. Furthermore, Comprehensive Nuclear-Test-Ban Treaty (CTBT) related research is done. Meteors are one of the few natural impulsive sources generating energy in kT TNT equivalent range. Therefore, the study of meteors is essential to the CTBT where infrasound is applied as monitoring technique. Studies of meteors in the Netherlands have shown the capability of infrasound to trace a meteor through the stratosphere. The propagation of infrasound is in first order dependent on the wind and temperature structure of the atmosphere. The meteor's path could be reconstructed by using ECMWF atmospheric models for wind and temperature. The results were compared to visual observations, confirming the location, direction and reported origin time. The accuracy of the localization mainly depends on the applied atmospheric model and array resolution. Successfully applying infrasound depends on the array configuration that should be based on the -frequency depend-spatial coherence of the signals of interest. The array aperture and inter-element distance will play a decisive role in detecting low signal-to-noise ratios. This is shown by results from studies on volcanic infrasound from Mt. Etna (Italy) detected in the Netherlands. Sub-array processing on the 16 element array revealed an increased detectability of infrasound for small aperture, 800 m, arrays, compared to large aperture, 1500 m, arrays.

U32B-04 1440h

Infrasound from Bolides: Inverse Remote Sensing

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The entry of large meteor-fireballs (bolides) into the atmosphere generates numerous physical phenomena that allows its detection including the generation of substantial amounts of heat, light, propagating blast waves, dissociation, ionization, aerosols, remnant wake turbulence, upward propagating ionospheric waves, VLF radio wave emission, etc. The low frequency remnant of the blast wave at great range (from 10 Hz to as long as a few minutes in period) can be detected by ground-based infrasonic pressure sensor arrays at ranges of hundreds to tens of thousands of kilometers depending on the kinetic energy of the bolide and on local wind-noise. The multiple array detection allows the location of the source to be determined (latitude, longitude) with uncertainties in the determined great-circle bearing increasing substantially beyond about 10,000 km in range. A reverse ray tracing or ray-mode analysis can also allow the range and altitude of the source to be estimated as well even with data from only a single array. While these IMS ongoing detection's will add new and different types of bolides to the already existing database regarding the global influx rate, the data can also be used to ascertain detailed properties of the bolide. Using this information in combination with realistic models of entry and possible satellite detection's, we can also infer detailed aspects about the bolide's properties. We will review this detection problem utilizing infrasound data from some recent events and in combination with ground-based cameras/radiometers detections.

U32B-05 1455h

The Effect of Atmospheric Variability on Infrasound Propagation

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Natural changes in the background atmospheric state variables greatly influence infrasonic signal propagation characteristics on time scales from hours to months and over horizontal spatial scales greater than about 750 km. Complexity arises from inherent atmospheric variability across all levels. Using state-of-the-art acoustic propagation codes and measured atmospheric profiles, the influence of atmospheric variability on infrasound signals is modeled and discussed. Several illustrative examples are presented. Calculations of the temporal evolution of the propagation characteristics for representative locations and time intervals are shown. In addition, instantaneous global maps of the percentage of signals ducted in the troposphere, stratosphere, and lower thermosphere, as well as escaping to ionospheric levels, are presented. The prospects for using observed infrasonic signals to infer the state of the atmosphere is also discussed.

U32B-06 1510h

Modeling of Seasonal Trends in Infrasound from Rocket Events

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Infrasonic energy from moving sources has been observed at ranges exceeding 1000 km and for propagation environments that support both stratospheric and thermospheric ducting. Successful modeling of these types of observations relies on adequate representation of both the source and the atmospheric characteristics along the propagation path. In this study, predictions of signal arrival time and azimuth are compared to long-range observations of infrasound from rocket events with known trajectories. Seasonal trends are observed in the data, and these trends are successfully modeled using ray theory, discrete sampling of the moving source, and climatological representations of the atmosphere. Predictions are also made using assimilation of climatology and synoptic models below 40 km.
Sponsored by Air Force Research Laboratory, Contract DTRA01-01-C-0084

U32B-07 1525h

Infrasound Associated with the 3 November, 2002 Alaskan Earthquake

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Infrasonic waves associated with the November 3, 2002, magnitude 7.9 earthquake in Alaska were detected by the microphone array (I53US) in Fairbanks, Alaska. The epicenter of the earthquake lay some 135 km south of the Fairbanks array. Both seismic and acoustic signals were recorded successively by the microphone array. The fault rupture of the earthquake moved east-southeast along the Denali-Totschunda system fault for approximately 320 km. The northern side of the fault moved to the east and vertically upward relative to the southern side. Displacements up to 8.8 meters were measured at various points along the fault. The seismic P-wave signal arrived at the array approximately 27 seconds after the epicenter shock with a trace velocity of 5 km/sec. This was followed, some 12 minutes later, by an infrasonic wavetrain that had an average trace velocity of 0.34 km/sec and lasted about ten minutes. The azimuth of arrival of the infrasonic waves steadily moved eastward throughout the wave train apparently following the rupture's leading edge along the fault. The largest infrasonic signals, reaching over 12 Pa, came from the azimuth of the regions of the largest ground motion along the fault. The source of the infrasound is taken to be the sudden local motion of the mountains in the Alaska Range along the Denali fault as they responded to the eastward propagating fault structure.

U32C MCC: 3016 Wednesday 1600h

Recent Infrasound Studies, Phenomena, and Development III

Presiding: **D McCormack,** Geological Observatory of Canada**; D Drob,** Naval Research Laboratory

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U32C-01 1600h INVITED

Six-years review of infrasound monitoring and studies at the French NDC

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The French NDC currently receives data from 7 IMS-type infrasound stations installed in various environments. Continuous automatic processing of the data is being performed in the [0.02-4] Hz frequency band in order to detect and characterize coherent infrasonic waves recorded on the arrays. In parallel, infrasonic background noise systematically measured in different frequency bands and correlated to local variations of wind speed, allow a geophysical monitoring of both equipment and processing results. The influence of wind-noise fluctuations on the detectability will be discussed. Examples of coherent infrasonic waves generated by strong earthquakes occurring within region of high mountains will be presented. Thorough analyses of ground-coupled air waves allow the evaluation of the relative contributions of the different source mechanisms involved in large earthquake. Using appropriate acoustic propagation models derived from realistic atmospheric profiles, the inversion of the infrasonic measurements is used to reconstruct secondary source regions. Recent developments on infrasound data processing at the French NDC concerning advanced classifier methods, propagation modeling including spatio-temporal variability of atmospheric profiles and source location procedure using multiple arrays will also be presented.

U32C-02 1620h INVITED

An Optical Fiber Sensor for Low-frequency Acoustics

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We have developed a new distributed sensor for detecting pressure variations in the atmosphere. The instrument reduces noise due to air turbulence by averaging pressure along a line by means of monitoring strain in a long, sealed, tubular diaphragm with an optical fiber interferometer. A pair of optical fibers is wrapped in a spiral along the length of the tube. As the air pressure outside the tube changes, the associated strain in the tube (and fibers) is sensed by means of a Mach-Zender interferometer. Above 1 Hz, the optical fiber infrasound sensor (OFIS) is less noisy than microbarometers relying on mechanical filters. The records we have collected from an 89 m long OFIS indicate a new low noise limit in the band from 1 Hz to 10 Hz. At frequencies above the range of microbarometers, the OFIS is quieter than the best low-frequency microphones. Because the OFIS integrates pressure variations at light-speed rather than sound-speed, phase delays inside the sensor are negligible.

U32C-03 1640h INVITED

Detection of atmospheric acoustic-gravity waves through ionospheric measurements using dense GPS arrays

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The Global Positioning System (GPS) is now widely used to measure ionospheric electron content at both global and regional scales. It is also capable of detecting small-scale high-frequency ionospheric disturbances caused by atmospheric acoustic-gravity waves. We show examples of ionospheric perturbations caused by earthquakes, rocket launches, and large surface explosions. The neutral atmospheric waves triggered by these events couple with the motion of free electrons and ionized plasma at ionospheric heights and induce coherent fluctuations of electron densities and ionization layer boundaries that are detectable with GPS. In all cases, the ionospheric perturbations match fairly well observations made through other techniques as well as numerical models. The development of permanent networks of densely spaced and continuously recording GPS stations open up new opportunities for the study of infrasonic waves in the atmosphere and their coupling with small scale processes in the ionosphere. We show examples of infrasonic waves detected using the 250-station GPS network that covers the Los Angeles area (SCIGN). Although the signal-to-noise ratio of these perturbations is relatively small, we show that it can be considerably improved by multi-station array processing techniques derived from seismic array analysis. These techniques can also be used to determine the perturbation propagation azimuth and velocity and, eventually, to recover information about the sources of these perturbations.

URL: http://www.eas.purdue.edu/~calais/projects/ionosphere.html

U32C-04 1700h

Acoustic-Gravity Waves Induced by Earthquakes: Insights From Observations and Numerical Modeling

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Surface waves emitted after large earthquakes are known to induce, by dynamic coupling, atmospheric infrasonic and gravity waves propagating upward in the atmosphere. Those waves can be detected at ionospheric heights using a variety of techniques, such as Doppler or GPS ionospheric sounding, facilitating systematic monitoring. This opens new perspectives for remote sensing of solid earth events, or the study of solid Earth and atmosphere structure. However, in order to obtain quantitative information from these data, propagation effects due to the atmosphere must be separated from those due to the solid Earth structure. We present a number of modeling approaches to study the relative contribution of source mechanism, solid Earth and atmospheric structure, viscous dissipation and thermal conduction on the propagation of these waves. In order to validate these models, we tested our simulations with some benchmarks cases of simple solid or atmospheric source, as well as with several recent ionospheric observations of earthquakes.

U32C-05 1715h

On the Possible Infrasound Generation by Sprites

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Energetic electrons accelerated by electric fields in thunderstorms are assumed to be responsible for generation of luminous phenomena at altitudes above 30 km, so called sprites. If the generation of light in these phenomena is associated with local heating, it may also be expected that low frequency acoustic waves will be generated. Due to the cylindrical structure of the source the most of the acoustic energy will be radiated close to the horizontal plane along the entire height of the source. The infrasound from these phenomena is therefore unlikely to be detected immediately beneath the source. The search for infrasonic signals from the high altitude luminous phenomena was carried out during the recent years using data from the infrasonic network operated by the Swedish Institute of Space Physics. During the night of May 26-27 1995, when a severe thunderstorm area passed over the Golf of Bothnia, it was possible to identify signals, most probably generated by sprites. The infrasonic observations made during that night are described in the present report. Similar, chirp-like signals were observed during some other occasions at Swedish stations during the recent years.

U32C-06 1730h

Constraining volcano eruption dynamics with infrasound

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Infrasonic airwaves produced by exploding volcanoes provide an indispensable tool for understanding dynamics of diverse eruptions. Unlike the seismicity generated during eruption, which is a complex superposition of internal and surface source and wave propagation processes, the infrasonic pressure field can be unequivocally associated with the flux rate of gas released at the volcanic vent. Because the atmosphere does not support shear waves, and internal scattering, topographic echoes, site, and weather effects are substantially predictable, it is possible to objectively compare the infrasound, and assess degassing from diverse volcanic systems. With its utility for continuously tracking eruptive activity, even when line-of-sight view to the vent is obscured, infrasound greatly enhances the efficacy of volcano monitoring and interpretation of conduit processes / eruption dynamics. We showcase new results from Erebus, Fuego, Villarrica, and Santiaguito volcanoes to demonstrate the utility of infrasound for recovering quantitative parameters, such as eruption duration, source dimensions and mechanism, and explosive gas release. At Erebus, infrasound can constrain the physical dimension of enormous bubbles, with diameters up to 10 m and containing more than 1000 kg gas, that burst individually and infrequently from the lava lake surface. At Villarrica, longer-duration infrasonic transients reveal the eruptive mechanism to be a succession of gas slugs bursting from the free surface, occurring at 60-90 s intervals and representing a stable long-term mode of degassing. At Fuego, the infrasound associated with vigorous explosions is inferred to result from the fragmentation of a bubble foam layer, which continues for tens of seconds until the gas foam is depleted. And at Santiaguito, large eruptions, which generate low intensity infrasound, suggest a diffuse source region with dimensions comparable to the radiated infrasonic wavelength (vent radii > 100 m). The recorded infrasound from these 4 volcanoes complements our infrasound archives for an additional 6 volcanoes, which encompasses a wide range of eruptive behaviors. Infrasound recorded within a few km of a volcanic vent thus provides an ideal tool for objective comparison of associated degassing.

U32C-07 1745h

Hawaiian Infrasound: A Mele of Fire, Wind, and Water

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Some of the more interesting infrasonic signals the can be routinely observed in Hawaii are associated with volcanic activity, severe weather, and ocean processes. Kilauea volcano is one of the most active volcanoes in the world, and infrasonic observations from an expedition in November of 2002 strongly suggest that continuous infrasound in the 1-8 Hz frequency band may be generated from the lava tube system of Puu Oo and may correspond to pressure instabilities in the magma flow. The eruption signal we observed corresponds to low-level effusive activity, and appears to only propagate for a few tens of kilometers. In contrast, signals associated with severe weather in the ocean may propagate for thousands of kilometers. These infrasonic signals, known as microbaroms, are close relatives of microseisms and occupy the 0.1-0.6 Hz frequency band. We believe that these signals are generated by the nonlinear interaction of ocean surface waves generated by storms, and show some observations from hurricanes Daniel and Jimena. When these waves hit the Hawaiian coastline, they can produce world class surf as well as substantial infrasonic energy. We postulate that surf infrasound can be generated by the collapse of the wave upon itself (barreling), impact against a cliff, or slamming against a shallow reef, and show examples from the epic 2002-2003 Hawaiian winter. Our observations in Hawaii demonstrate how infrasound can provide useful information of solid earth-ocean-atmosphere interactions and can be integrated with other technologies to enhance our basic understanding of geophysical processes.

URL: http://www.inframatics.org

U41A MCC: 3001-3003 Thursday 0800h

The Core-Mantle Boundary: Theoretical, Experimental, and Observational Constraints I

Presiding: **J A Van Orman,** Case Western Reserve University**; A D Brandon,** NASA Johnson Space Center

U41A-01 0800h INVITED

Constraints on Chemical Interaction Between Core and Mantle

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Chemical reactions between the core and mantle have been suggested to explain a variety of phenomena including the D" layer (e.g., Knittle and Jeanloz) and Os isotopic signatures observed in some plume derived magmas (e.g., Walker et al.). However, the chemical nature of a core-mantle interaction depends on several poorly constrained factors such as how close the core and mantle are to chemical equilibrium, the composition of the core (i.e., the identity of the light element(s)), and partitioning of elements between the inner and outer core. The state of equilibrium between the core and mantle is dependant on the mode of core formation: Did the core continually re-equilibrate with the mantle as it formed while the Earth grew, or did core metal equilibrate with mantle silicates at pressures significantly lower than those of the present day core-mantle boundary (for example as in the model of Righter et al.)? In addition any subsequent differentiation of the mantle resulting in the formation of D" (if it is not a direct reaction product between core and mantle) could change the state of equilibrium between the core and mantle especially the development of a zone of partial melt as suggested by the ULVZ. However, experimental studies to date of interactions between the core and mantle have assumed that D" is solid and of similar composition to the rest of the mantle (i.e., Knittle and Jeanloz, Goarant et al., Hillgren and Boehler). All that is known about the composition of the core is that it is Fe alloyed with some lighter element. The identity of the light element is unknown (although there is only a limited number of reasonable candidates) and the amount of that element is dependent upon its identity. The identity of the light element is also critical for determining how elements might partition between the inner and outer core. Recent experimental and theoretical work on core-mantle interaction, light element in the core, and partitioning at very high pressures will be reviewed. Ref: Goarant et al. (1992) JGR 97, 4477. Hillgren and Boehler (2000) AIRRAPT 17, 609. Knittle and Jeanloz (1989) GRL 16, 609. Righter et al. (1997) PEPI 100, 115. Walker et al. (1995) Science 269, 819.

U41A-02 0815h

Progress in the Development of Techniques for Detection of Chemical Interactions Between the Core and Mantle

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If some plumes arise from the core-mantle boundary and there is limited chemical interaction between the core and mantle within D", it is possible that these plumes could contain a unique chemical or iso-topic fingerprint that is characteristic of the core. Unequivocal identification of a core component in a plume could potentially settle a major question in geodynamics. The ideal tracers of a core component in a plume are elements that occur in very high abundance in the core relative to the mantle and crust. The most sensitive suite of elements for identifying possible core contributions to plumes that may arise from the core-mantle