viable. While it is well known that the byproduct of energy produced from hydrogen is water vapor, it is not well known that the storage and transfer of hydrogen is inevitably accompanied by measurable leakage of hydrogen. Unintended consequences of hydrogen leakage include reduction in global oxidative capacity, changes in tropospheric ozone, and increase in stratospheric water that would exacerbate halogen induced ozone losses as well as impact the earth's radiation budget and climate. Stratospheric ozone depletion would increase exposure to harmful ultraviolet radiation and increased risk to melanoma. We construct plausible global hydrogen energy use and leak scenarios and assess their impacts using global 3-D simulations by the Model for Ozone And Related Trace species (MOZART). The hydrogen fluxes and photochemistry in our model successfully reproduce the contemporary hydrogen cycle as observed by a network of remote global stations. Our intent is to determine environmentally tolerable leak rates and also facilitate a gradual phasing in of a hydrogen economy over the next several decades as the elimination of the use of halocarbons gradually reduces halogen induced stratospheric ozone loss rates. We stress that the future evolution of microbial soil sink of hydrogen that determines its current lifetime (about 2 years) is the principal source of uncertainty in our assessment. We propose global monitoring of hydrogen and its deuterium content to define a baseline and track its budget to responsibly prepare for a global hydrogen economy.

## U32A-0035 1330h POSTER

### The Dynamics and Characteristics of Aeolian Dust in Dryland Central Asia: Possible Impacts on Respiratory Health in the Aral Sea Basin

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Over the last 40 years over 36,000 km2 of the former Aral Sea bed have been exposed creating a potentially significant aeolian dust source. It is widely believed, but little researched, that increased dust storm activity in the region has had a major impact on human health. In this paper we report the findings of a study into the link between dust exposure and respiratory health amongst children in the Autonomous Republic of Karakalpakstan, located on the southern shore of the Aral Sea.

Data were collected over a 12 month period at 16 sites located within a broad transect running north to south through Karakalpakstan. At each site monthly measurements of dust deposition were undertaken linked with daily meteorological data at 6 stations. At 3 sites weekly measurements of PM10 were also carried out. Approximately 100 children (aged 7-10 years) were randomly selected within 5 km of each dust trap site and data were collected on their respiratory health and environmental exposures. Lung function data were also collected using a handheld spirometer. A linear regression model was used to predict lung function for the children incorporating variables for Forced Expiratory Volume in one second (FEV1), age, gender, height and weight and we estimated the impact of dust deposition rates on the odds of having abnormal lung function using logistic regression.

The findings indicate that dust deposition rates across the region are high with sites located near the former shore of the sea being the worst affected. For these northerly regions the former Aral Sea bed is the most likely source of dust. The situation for the rest of the country seems to be far more complex. In these regions it appears that local sources (agricultural fields, abandoned irrigation grounds, overgrazed dunes, and unpaved roads) and more distant sources to the south and south-west represent significant sediment providers, particularly in the early summer when agricultural fields are ploughed. We found some evidence of a dose-related impact of dust levels on lung function. These associations were statistically significant for all measures of dust exposure but were most marked for levels of winter dust exposure and level of PM2.5 exposure.

The results from this study suggest that aeolian dust dynamics in the region are spatially and temporally highly variable and, counter to local and regional perceptions, the former bed of the Aral Sea does not appear to be the only significant source. Nevertheless, there is also evidence of a dose-related impact of airborne dust on the risk of having abnormally low lung function in children living in the Aral Sea Area.

## U32B MCC: 3016 Wednesday 1340h

### Recent Infrasound Studies, Phenomena, and Development II

*Presiding:* **C Hayward,** Southern Methodist University; **M A Hedlin,** Laboratory for Atmospheric Acoustics, Institute of Geophysics and Planetary Physics, University of California, San Diego

## U32B-01 1340h INVITED

### Charting a Course for the Infrasound Renaissance

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The turn of the 21st century marks the onset of a renaissance in the field of infrasound, which had been dormant for 30 years. The ongoing deployment of a global infrasound network has reawakened the field to a world of high-resolution digital array data, rapid communication, and seemingly unlimited growth in computing power. Complex phenomena that could only be addressed in general terms three decades ago can now be measured, analyzed, and modeled with unprecedented fidelity. Many fundamental problems in infrasound are now being revisited, and infrasonic observations are being integrated with other technologies (such as seismic, strainmeter and infrared) for the discovery of new phenomena or the refinement of geophysical studies. On July 24-25, 2003, the National Science Foundation sponsored a group of infrasound experts and interdisciplinary researchers to convene in Waikoloa, Hawaii, and chart a course for basic US infrasound research. The conveners selected key projects that would lead to significant advances in our understanding of infrasound generated by effusive and explosive volcanoes, ocean swells, bolides, fauna, severe weather, and long-period atmospheric instabilities. Projects were also proposed to refine our knowledge of atmospheric dynamics and transport mechanisms. A sampling of these projects is discussed in light of their contributions to our fundamental scientific understanding and their impact on the geophysical community.

URL: http://www.inframatics.org

## U32B-02 1400h INVITED

### Report to the Department of Defense on Infrasonic Re-entry Signals From the Space Shuttle Columbia (STS-107) (Revision 3.0)

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Infrasound signals recorded by ten stations during the reentry of Shuttle STS-107, are analyzed in an attempt to better understand the cause of this tragedy. These prototype infrasound stations recorded clear signals from this shuttle as well as from several previous missions. As sound passes through the atmosphere, stratification of winds and temperature as well as turbulence modifies the received signal. Sound propagating from source to receiver along different paths can arrive at the receiver at different times giving rise to bursts of signal. A single impulsive event such as a shock wave or an explosion might give rise to several clear receptions. Consequently, it is difficult to separate nearby events from atmospheric multi-path effects. Below and to each side of the shuttle path, there is a sonic boom carpet. Receivers within this carpet recorded the Shuttle's sonic boom, while outside the carpet, signals similar to those from subsonic sources were observed. These infrasound arrays can determine the direction of the signal. When combining these data with the trajectory of the shuttle, we find the primary signal is located from near the direction of the shuttle's closest approach (or slightly West of that location) to within the few tens of km accuracy usually associated with infrasound localizations. This means that there do not appear to be other sources of infrasound in the vicinity of the shuttle. All stations observed multiple arrivals associated with sound generated during the approach of the shuttle. These arrivals may be explained by multiple paths through the atmosphere but it is possible that some come from fragments or debris. The U. S. infrasound community has not examined in detail shuttle reentry signals in the past so it is difficult to identify anomalies in the signal. Our analysis team compared signals recorded for STS-107 to flights STS-77, STS-78, and STS-90 which had similar re-entry trajectories but fewer infrasound stations on line. The sonic boom waveforms from each mission were different in detail but essentially the same in major features. Noticeable differences in the STS-107 signals were an especially long (almost an hour) acoustic signal following the sonic boom coming from the West. There was a less clear indication of a change in the recorded waveform over the CA-NV border region. There is insufficient data from previous missions to determine if such a change is expected.

### 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.
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### 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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