Infra Matics
The Newsletter of Subaudible Sound

Number 01 March 2003

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Introducing inframatics.org

Background

In 1883, the Krakatoa volcano awakened the world to the existence of sub audible sound waves in the atmosphere. These waves, known as infrasound, can travel thousands of kilometers and are readily detected by sensitive microbarometers. We now know that a wide variety of other atmospheric phenomena, including tornadoes, landslides, earthquakes, meteors, aurora and atmospheric turbulence, and man-made sources, including atmospheric nuclear tests, rockets and supersonic aircraft, also generate infrasound. These long-period sound waves were of great interest in the 1950's and 1960's during the era of atmospheric nuclear testing. Interest waned as the Limited Test-Ban Treaty pushed nuclear testing underground. The Comprehensive Nuclear Test-Ban Treaty rekindled interest, however. This treaty bans all nuclear tests and establishes a monitoring network of sensors that probe the Earth's solid interior, oceans and atmosphere for unusual signals. The infrasound network will offer us an unprecedented opportunity to better understand man-made and natural atmospheric phenomena on a global scale. We anticipate that this global network of listening posts monitoring Earth's atmospheric shell will some day become as indispensable as the global seismic network that monitor's Earth's solid interior.

(continued on page 2)

Inframatics Editorial Board

Inframatics is an informal series to make available in a timely fashion information about the science of infrasound that any of us might develop. It is provided via our organization's website www.inframatics.org. We expect contributions to inframatics to be short and cover only one distinct subject. Figures can be hand-drawn. Lengthy formulae can be stated without derivation. Contributions should be sent to any member of the editorial board by electronic mail. We will assemble all contributions received during a quarter into a single newsletter. The information may be duplicated in the website. We expect that all of us will publish papers that use the material we have previously forwarded to inframatics. Everyone is encouraged to do so. To avoid having the material used by someone else in earlier publication, we require that permission to use the material contained in the inframatics newsletter by anyone other than the author requires permission by the inframatics editorial board. For the time being, Michael Hedlin will act on behalf of the editorial board in such matters.

The organization and website

The new inframatics organization provides information about the use of sub audible sound waves in the atmosphere for studying natural atmospheric phenomena and monitoring anthropogenic sound sources including clandestine nuclear tests. The main product of this organization's website (www.inframatics.org) is this newsletter that includes articles summarizing ground breaking research in low-frequency atmospheric acoustics. Our primary research goal is to learn how we can use low-frequency sound waves to characterize distant natural and man-made atmospheric events. With this goal in mind, research continues on how sound propagates through our unsteady atmosphere and how clear recordings of distant events can be made despite noise due to atmospheric turbulence. Researchers are improving our models of the atmosphere and are collecting information about significant atmospheric sources to provide a basis for this research. In addition to presenting new research results, the newsletter also provides updates on construction of the global infrasound monitoring network and communications system. The newsletter also provides other information that we expect will be of interest to the international infrasound community including information about new opportunities for funding and information about past and upcoming meetings.

Given the rapid pace at which this field is evolving, the inframatics.org website will also provide continual updates to the information found in the quarterly newsletter as well as information about this field in the popular press, updates on personnel movements and links to related sites on the internet. The website also provides an opportunity for those who build and operate infrasound arrays to report problems or innovative solutions to these problems.

Monitoring Volcanic Eruptions with Infrasound

Milton Garces

There exist rich yet inaudible volcanic soundscapes pulsating below the human hearing range. These infrasounds are vital, dynamic manifestations of Earth's blood-stream, and can enhance our assessment of volcanic threats.

Eruptions are driven by excess pressure within a volcano's circulation system, and infrasounds carry information about large perturbations within this system. These pressure perturbations vary greatly in scale and character, but generally occur within some volcanic fluid, be it gas, water, or magma. Exploding bubbles, rapidly expanding gas, resonating cavities, twists in the magma plumbing, standing waves within lava lakes, bubbles pulsating within a lava flow or crater lake, lava falls, and high-speed gas jets can all alter the register and timbre of a volcano's voice, so no two volcanoes sound exactly alike. The larger the size of the source region, the lower the pitch of the sound that can be generated. Depending on the size and intensity of the source, infrasonic waves can propagate for very large distances. A typical explosion at Stromboli volcano would generate short-lived infrasonic pulses that would only be recorded a few tens of kilometers from the source, but a cataclysmic Plinian eruption can be observed around the world and be recorded for hours.

Figure 1. Fumaroles often generate an audible roaring sound. Although their gas temperatures and speeds can be extremely high, the extreme values are often restricted to a very well defined jet. One of the fumaroles in Kuju Volcano, Japan, ejected rocks that were tossed into its vent.

Figure 2. Skylight at Pu'u O'o volcano, Hawaii. It is through such skylights and similar vents in the crater of Pu'u O'o that infrasonic signals can be radiated into the atmosphere.

Because infrasonic signals propagate in the atmosphere, a volcano should have an open vent to efficiently radiate infrasound. This is often the case during an ongoing eruption, when the threshold level for an evacuation may be determined by the degree and intensity of activity. Infrasonic surveillance is of particular value in circumstances where the source is either hidden or unreachable. Such is the case during cloudy conditions and when sources are buried within subterranean magma reservoirs and conduits.

Despite the uniqueness of each volcanic voice, some infrasonic signals are typical of the different types of activity. At the pre-eruption stage or in the periphery of a volcano, fumaroles can generate infrasonic signals that are determined by the gas properties and the conduit shape. Hawaiian eruptions usually produce a fairly steady flow of magma. Fluid flow noise from lava moving and

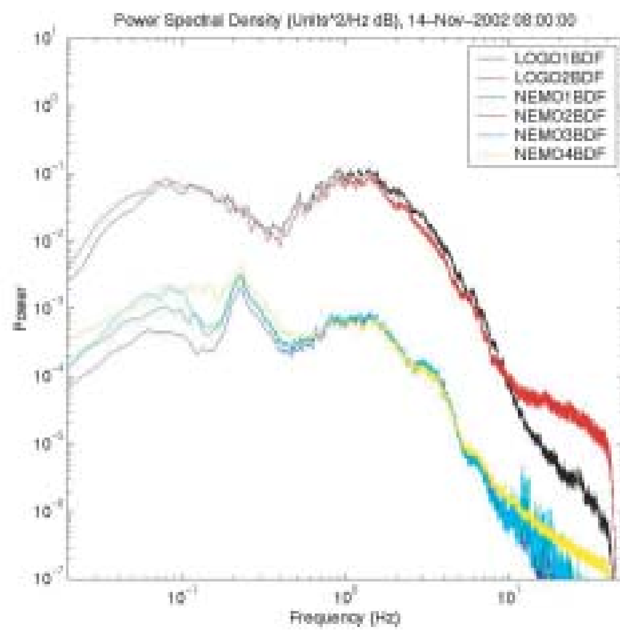

Figure 3. Power Spectral Density of infrasonic for six microphones deployed temporarily near Pu'u O'o volcano, Hawaii, under relatively low wind conditions (<6m/s). The closest sensors were LOGO1 and LOGO2, located at the exposed crater rim and ~0.1 km from the active vents. NEMO1-4 were located ~2km from the vent within a forested section. The tremor signal can be observed as a broad peak with maximum between 1 and 2 Hz. Under high wind conditions (>10 m/s) at the crater, only NEMO1-4 could consistently observe the tremor peak.

cascading through torturous, multi-level conduits may enliven the tonal character of an eruptive stage. However, even these relatively quiet eruptions can generate a continuous infrasonic vibration, known as tremor, that can be measured both in the atmosphere and in the ground. A recent infrasonic experiment at Pu'u O'o, the active vent of Kilauea Volcano, demonstrated that significant coherent infrasonic tremor is radiated by the ongoing effusive eruption. Like its well-documented seismic counterpart, it is possible that this infrasonic tremor has been radiated since the 1983 onset of the Pu'u O'o eruption, but has remained undiscovered until now. The spectral content of tremor signals has been attributed to the acoustic resonance of magma-gas mixtures, and may be used to infer the gas content of the melt and the character of the excitation source.

Occasionally, Hawaiian eruptions transition into Strombolian phases, heightened levels of activity characterized by explosions and lava fountains. Strombolian eruptions can be acoustically recognized by modulated amplitudes punctuated by sporadic sharp concussions, high-frequency jetting, and occasional displays of harmonic tremor. Although tremor is endemic to most volcanoes, harmonic tremor is exceptional in its instrument-like timbre. Infrasound from Hawaiian and Strombolian eruptions may be observed at ranges of tens of kilometers. As the ongoing 20 year eruption of Hawaii and the almost continuous two millennium eruption of Stromboli volcano demonstrate, it is possible to sustain relatively stable Hawaiian and Strombolian eruptions for long periods of time. Since these type of eruptions are relatively common and stable, high-fidelity

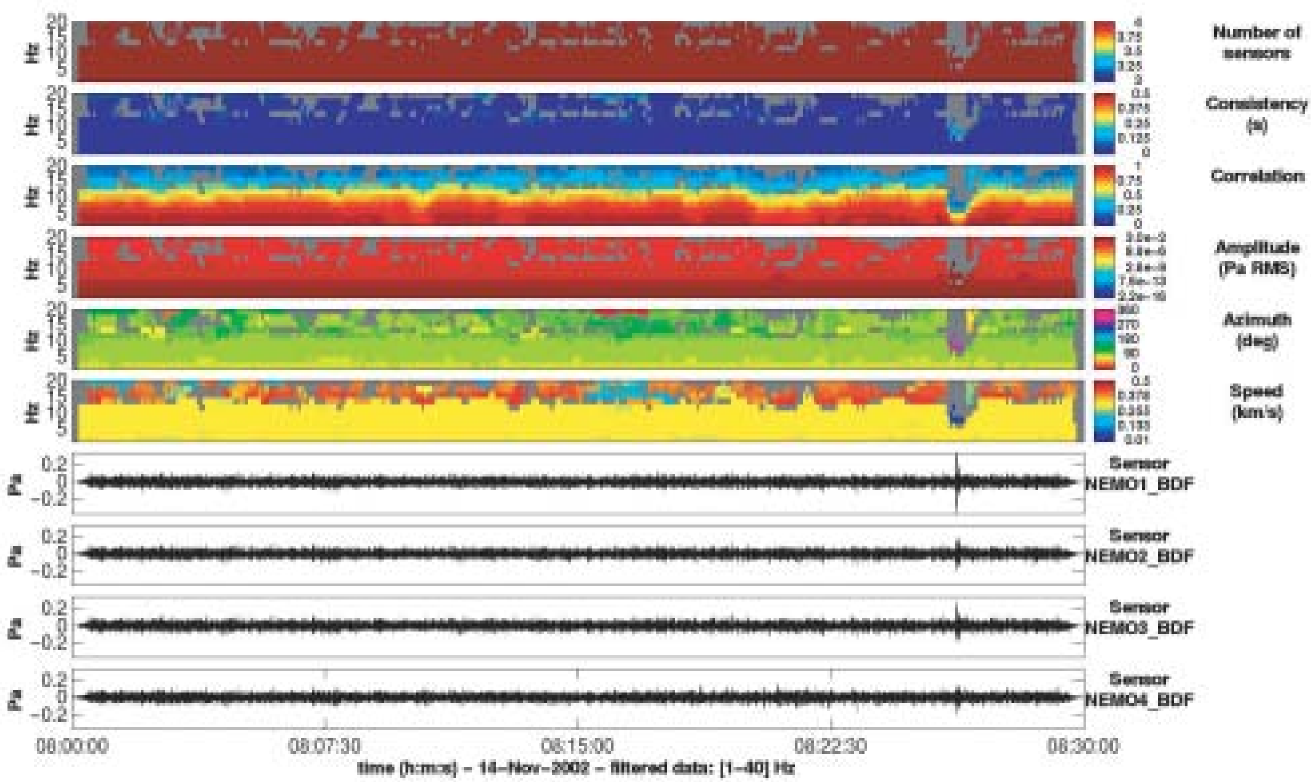

Figure 4. Progressive Multi-Channel Correlation (PMCC) results for a 4-element quadrilateral array with a maximum inter-element distance of 100 m and a minimum distance of 50m. The correlation across the array is greater than 0.5 below 10 Hz, and the azimuth points consistently towards the active vent. The low apparent phase speed below 10 Hz may be due to the small array aperture, uncertainties in the sensor locations, and differences in the phase response between the electret microphones. Note a helicopter around 8:26 UT is not detected because its apparent horizontal phase velocity is outside the specified detection ranges.

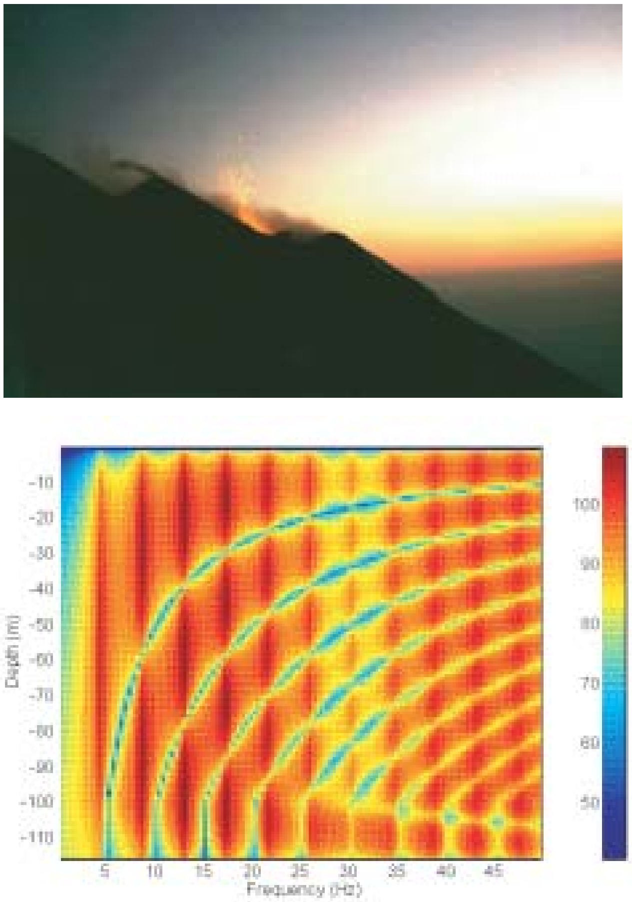

Figure 5. Stromboli volcano, Italy, is the most active volcano in the world. And explosion can excite infrasound in a magma conduit, leading to a modal structure typical of an organ pipe open at both ends. The lower figure shows the predicted modal amplitude of an explosive source placed at 100 m depth within the conduit of Stromboli.

acoustic records can be readily obtained. Studies of such records demonstrate that infrasound can provide quantitative estimates of the intensity, timing, progression, and perhaps the magma composition and material ejected during an eruptive episode.

At the next intensity level are Vulcanian eruptions, which may involve extremely high pressures and the supersonic flow of magma, gas, and rocks. Plinian eruptions are the bigger and meaner siblings of Vulcanian eruptions, although the transition between these two eruption types is blurred. Such violent eruptions tend to subject the volcanic edifice to destructive abrasion and break down some of the basic assumptions associated with linear acoustics. Both eruption types are capable of injecting material into the stratosphere and generating infrasound that can be observed thousands of kilometers away. At any time during an eruption, part of a steep volcanic edifice may collapse and fragment, entraining scorching avalanches of debris that may rapidly engulf valleys. Such pyroclastic flows can be detected and tracked by two or more infrasonic antennas, permitting an assessment of their size, duration, speed, and direction. Since cataclysmic Vulcanian and Plinian eruptions are scarce, most infrasound records available for this type of eruptions are low-resolution barometric records from meteorological stations. The Plinian eruptions of Mt. St. Helens (1980) and Krakatau (1883) were recorded by weather stations worldwide.

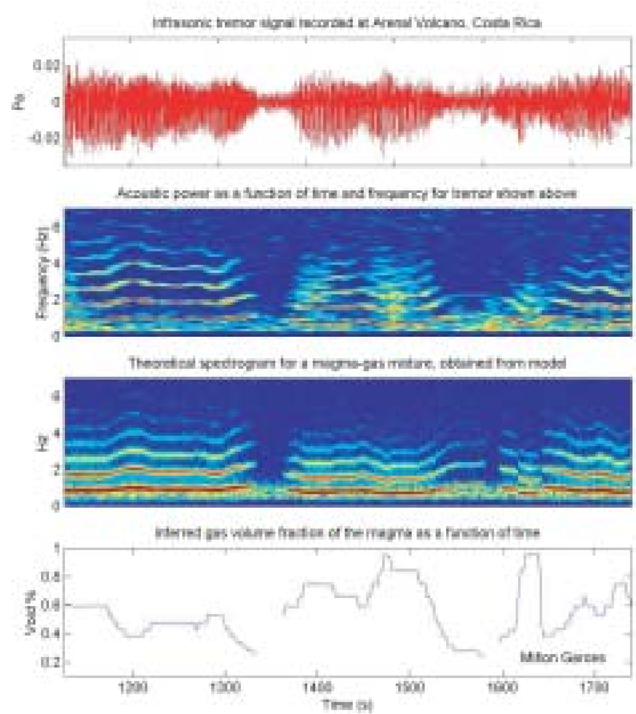

Figure 6. Infrasonic waveform, spectrogram, synthetic spectrogram, and inferred gas fraction for a harmonic tremor signal observed at Arenal Volcano, Costa Rica. The gliding in the spectral lines is attributed to changes in the gas content of a magma-gas mixture, which alters the sound speed and thus the resonance frequency of the magma conduit.

Technology already exists to perceive the subtle variations in tenor and intensity between eruption types. The global infrasound network that is part of the International Monitoring System (IMS) will permit the detection of eruptions anywhere in the world with an equivalent explosive yield of 1 kiloton or more, although some stations (Hawaii, Galapagos, and Japan, for example) will be able to detect much smaller eruptions from adjacent volcanoes. The deployment of two or more infrasonic antennas near a volcano would not only permit much lower detection thresholds and enhance the IMS network, but also allow tomographic studies of atmospheric variability using volcanic sounds as a source.

Suggested Reading:

Garcés, M., M. Iguchi, K. Ishihara, M. Morrissey, Y. Sudo, and T. Tsutsui (1999). *Infrasonic precursors to a Vulcanian eruption at Sakurajima volcano, Japan*. Geophys. Res. Lett., 26, 2537-2540.

Garcés, M. A., M. T. Hagerty, S. Y. Schwartz (1998). *Magma acoustics and time-varying melt properties at Arenal Volcano, Costa Rica*. Geophys. Res. Lett. 25, 2293-2296.

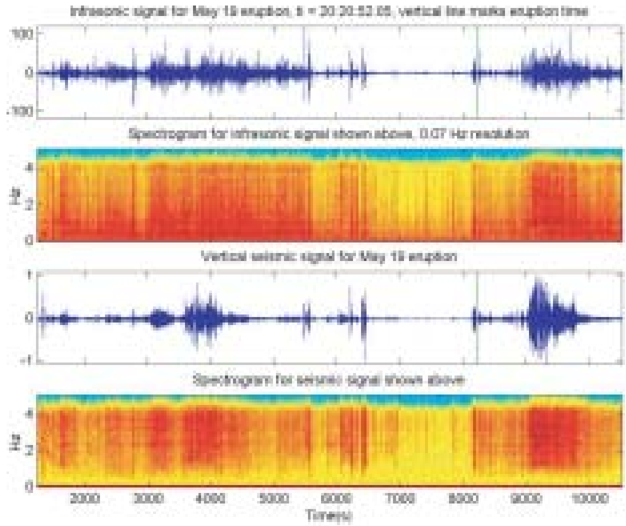

Figure 7. Infrasonic and seismic precursors to a vulcanian eruption at Sakurajima Volcano, Japan. The vertical green line denotes the time when an eruption alert was issued. The infrasonic records possess more information and are easier to discern than the seismic waveforms, which are often complicated by the torturous topography of the volcanic edifice.

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The Global INfrasound Archive - GINA

David McCormack
Laslo Evers

Given the current rapid development of the global infrasound network, there are exciting new research opportunities in many areas of infrasound, from array design to source identification to atmospheric profiling. To assist the scientific research community to exploit this new resource, the Geological Survey of Canada (www.seismo.nrcan.gc.ca) *and the Royal Netherlands Meteorological Institute*(www.knmi.nl) *are developing an infrasound event archive.*

The purpose of the archive is two-fold: first, to provide an open, unencumbered source of high-quality infrasound data for interested researches, and second to help raise the profile of infrasound amongst the acoustic, atmospheric and earth science research communities to encourage wider participation in infrasound studies.

Data will be accepted from any infrasound station operator who is prepared to make data freely available, and data will be organized by event as time series associated with relevant ancillary information such as station and source location information. The archive will be hosted at both the Geological Survey of Canada in Ottawa and at the Royal Dutch Meteorological Institute in De Bilt. Data will be made available to any interested researcher in a wide range of data formats including CSS3.0. Data access can be either interactive through a web interface or via AutoDRM. A prototype of the website is available at:

http://www.seismo.nrcan.gc.ca/nwfa/is_events/

This prototype is currently running only in Ottawa, and is currently populated only with data from the Canadian infrasound array at Lac du Bonnet, Manitoba.

Station operators interested in contributing data, and scientists interested in using data are encouraged to contact the authors at the above address.

Stand by for further developments!

GINA is made possible with support from the Nuclear Monitoring Project, Geological Survey of Canada and ORFEUS.

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Announcing a new acoustics lab at the University of California

Michael Hedlin

The Laboratory for Atmospheric Acoustics (L2A) has been established at the Scripps Institution of Oceanography (SIO) at the University of California, San Diego. Researchers at the lab are interested in acoustic source phenomenology, the propagation of sound through our turbulent atmosphere and the clear reception of sound waves despite variable, and often high levels of atmospheric noise. Although research at the lab has focused on the use of sub audible sound to monitor the atmosphere for nuclear testing activity, researchers at L2A anticipate further research involving man-made and natural phenomena at frequencies spanning the full acoustic spectrum.

Researchers at L2A are located at the Marine Physical Laboratory on Point Loma in San Diego, California and at the Institute of Geophysics and Planetary Physics at SIO in La Jolla, California. Most field experiments are conducted at the Infrasound Laboratory at Pinon Flat, California. (continued on page 8)

Dr. Jon Berger (email: jberger@ucsd.edu, voice:1 858 534-2889) with Dr Mark Zumberge is responsible for the development of a new distributed acoustic sensor . The sensor reduces noise due to air turbulence by averaging pressure along a line by means of fiber optic sensing of strain in a long tubular diaphragm. The Optical Fiber Infrasound Sensor (OFIS) is currently undergoing field tests. Dr Berger with Dr Michael Hedlin has designed several arrays in the new International Monitoring System (IMS) infrasound network and has built arrays in California and Washington State, USA.

Lewis Berger (email: lewis@mpl.ucsd.edu, voice:1 858 534-1786) with G. D'Spain, G. Rovner and M. Hedlin studies the propagation of sound through our atmosphere and optimal array design.

Clint Coon (email: ccoon@epicenter.ucsd.edu, voice: 1 858 534-8773) plays a key role in research at L2A by deploying and maintaining temporary experiment sites at the Infrasound Laboratory at Pinon Flat, California. Data from these experiments are telemetered in real-time to our lab in La Jolla. Clint also serves as the chief engineer responsible for the smooth operation of the International Monitoring System infrasound arrays I56US at Newport, Washington State and I57US at Pinon Flat, California.

Dr. Catherine deGroot-Hedlin (email: chedlin@ucsd.edu, voice:1 858 534-2313) conducts research in atmospheric noise, array data processing and the modeling of acoustic wave propagation.

Dr. Gerald D'Spain (email: gld@mpl.ucsd.edu, voice:1 858 534-5517) with Lewis Berger, M. Hedlin and G. Rovner, studies the propagation of sound through our atmosphere and optimal array design. Dr. D'Spain's research methods were originally developed for use in underwater acoustics. An important component of Dr. D'Spain's research is the collection of "ground-truth" data on acoustic sources.

Dr. Michael Hedlin (email: hedlin@ucsd.edu, voice:1 858 534-8773) conducts research in the reduction of noise due to atmospheric turbulence. Dr. Hedlin has studied noise reduction with mechanical spatial filters and wind barriers as well as the new fiber optic system developed by Drs. Berger and Zumberge. With G. D'Spain, G. Rovner and Lewis Berger, Dr. Hedlin studies the propagation of sound through our non-stationary atmosphere and the optimal design of infrasound arrays. Dr. Hedlin with Dr. Jon Berger has designed arrays for the IMS and has constructed two IMS arrays in the USA. Dr. Hedlin is the chair of L2A and is the primary point of contact for the lab.

Galina Rovner (email: glr@mpl.ucsd.edu, voice: 1 858 534-5384) An expert in the propagation of sound through turbulent media, Dr. Rovner currently studies the propagation of sound through our atmosphere and optimal array design with D'spain, Lewis Berger and Hedlin. Dr. Rovner acts as the L2A liason with the Russian infrasound research community.

Dr. Mark Zumberge (email: zumberge@spot.ucsd.edu, voice:1 858 534-3533) with Dr. Jon Berger is developing the new fiber optic sensor.

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The Family is Still Growing Up

Alberto Veloso

The CTBTO was established in March 1997 and about 4 months later the first staff members of the Infrasound Section arrived in Vienna to initiate work on the IMS Infrasound Network. This program started from zero since there were no existing stations in the global Infrasound Network. It was difficult at first since only a few institutions had any previous experience in this field. Initially, we had to determine the requirements for site surveys, place orders for field equipment, interview applicants for positions with the Infrasound Section and obtain authorization from the member States to start work in their countries. After some delay, the first site survey conducted by our staff using our new equipment was carried out in May 1998 at infrasound station IS09 in Brasilia, Brazil.

As of today, the progress on the establishment of the IMS Infrasound network is as follows: 10 stations certified of 15 that are sending data to Vienna, 13 stations under construction and 9 more stations in the contract negotiation phase. This represents a total commitment of approximately 60% of the global IMS Infrasound Network. This global network is being installed in a wide variety of environments and, as consequence, the array design varies from one station to another in order to optimize station detection capability. However, the infrasound equipment that is being installed has a relatively high level of homogeneity and this will facilitate the global maintenance of the network.

It is expected that by the end of 2003 about 10 more stations should be transmitting data to Vienna. In addition, several other stations should be certified. As result, a considerable portion of the network should be in place by the end of this year, including a regional infrasound network extending throughout the North and South America continents.

The family is still growing-up refers not only to the current number of stations that are continuously being added to the global infrasound network but also to the number of people involved in the rapidly expanding infrasound community. New members, more data, more research and more ideas are good ingredients for progress and will lead to new discoveries in the field of infrasound.

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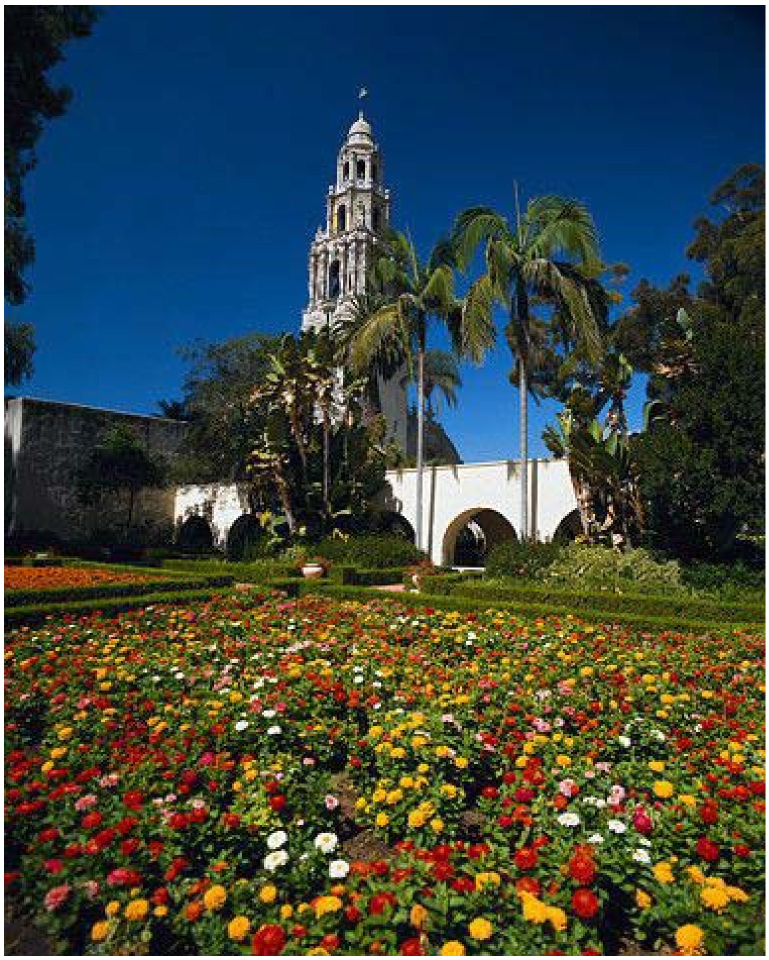
Announcing the 2003 Infrasound Technology Workshop

Michael Hedlin



Balboa Park in San Diego

Please mark your calendars. The 2003 Infrasound Technology Workshop will be held at the Laboratory for Atmospheric Acoustics at the Scripps Institution of Oceanography (http://www.sio.ucsd.edu/) in La Jolla, California from October 27 to October 30. A formal announcement will be made at the end of June.