Global monitoring of subaudible sound in Earth's atmosphere

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Abstract

Recent interest in monitoring nuclear weapons testing activity at all explosive yields has spurred development of a multi-pronged,global monitoring system. The new International Monitoring System (IMS) includes networks of instruments for monitoring Earth's solid interior, oceanic basins and atmosphere for evidence of nuclear testing. The networks operate continuously and give us the opportunity to also study non-nuclear phenomena.

The IMS infrasound network is entirely new and will comprise 60 arrays distributed nearly uniformly across the globe. Each array comprises between 4 and 8 elements with a baseline of 1 to 3 km. Due to ubiquitous atmospheric noise from turbulence, each element in an array is equipped with a spatial noise-reducing filter. The filters increase the ratio of coherent signal to incoherent noise by integrating pressure at 20 samples/sec across an area. Data from each element in a typical array are transmitted in real-time to a central facility and then via a satellite link to the International Data Centre in Vienna, Austria.

The infrasound community is tackling a wide variety of fundamental research problems dealing with the generation of subaudible sounds by both nuclear and non-nuclear sources, the propagation of sound waves through a turbulent atmosphere and the clear reception of faint signals from remote sources. This talk will provide an overview of the technical and research issues our community faces as it prepares to manage the enormous volume of data this network will provide and to exploit the data for nuclear monitoring and basic research.

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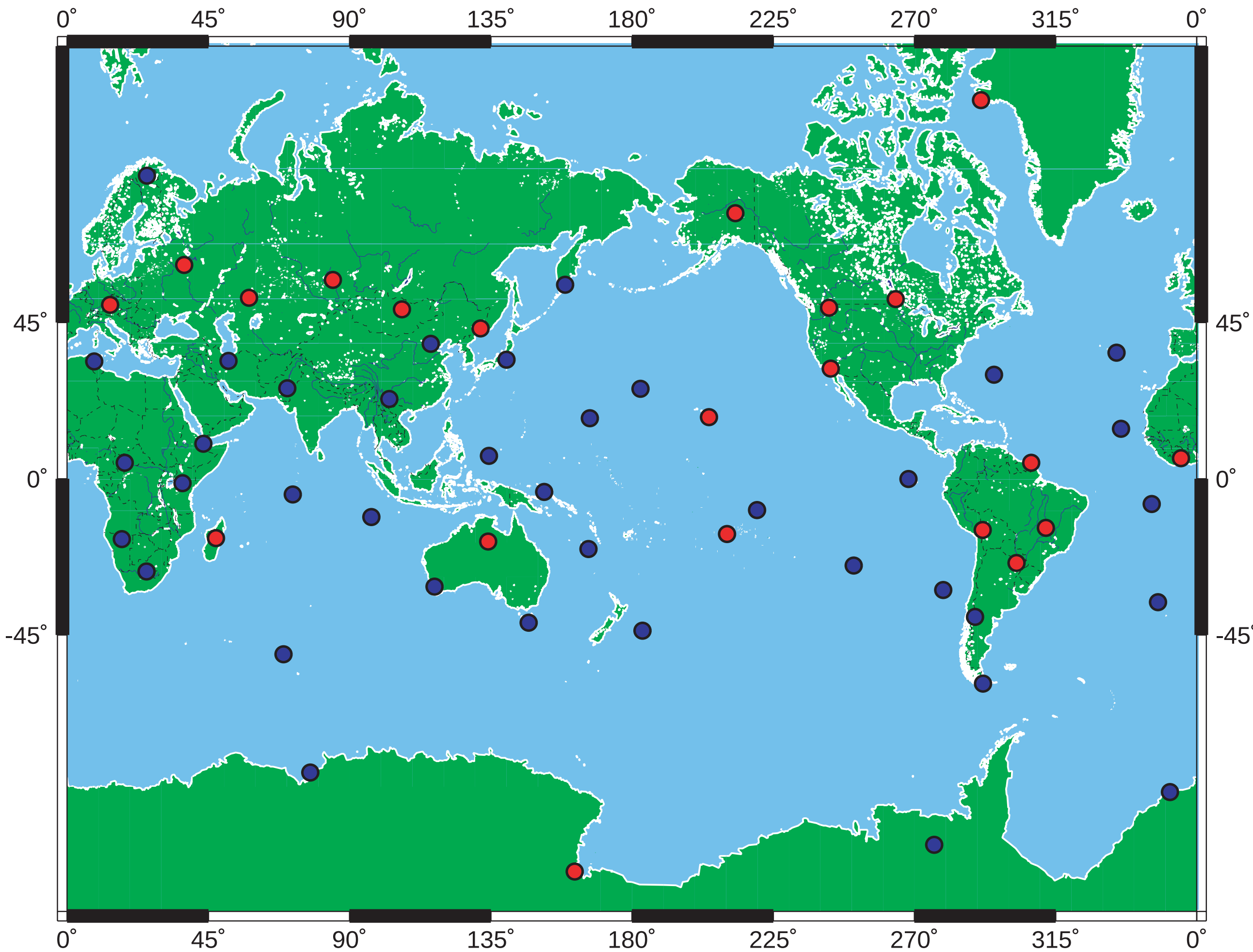

Figure 1. The International Monitoring System Infrasound Network. The stations that are existing or under construction are shown in red. The remaining stations in the global network are shown in blue. The network strives to provide uniform monitoring of the atmosphere above land and the oceans.

The New Global Infrasound Network

The Comprehensive Nuclear Test-Ban Treaty was tabled for signature at the United Nations in September of 1996. This has led to increased interest in monitoring globally for clandestine nuclear testing activity at all yields which in turn has led to the development of the 4-network International Monitoring System. When fully developed, the new infrasound component of the IMS will comprise 60 continuously operating microbarographic arrays (Figure 1). The operating arrays transmit data to the International Data Centre (IDC) in Vienna, Austria.

Each infrasound array includes between 4 and 8 elements with a baseline of 1 to 3 km (Figure 2). Infrasonic pressure data are collected at each site at 20 samples per second (sps) along with wind speed and direction sampled at 1 sps. All pressure data are filtered in the field by a spatial wind-noise-reducing system (Figure 3).

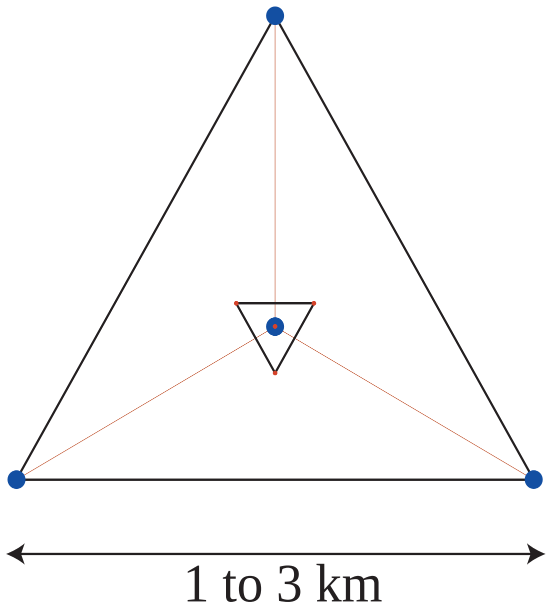

Figure 2. The prototypical infrasound array spans 1 to 3 km and is symmetric. In practice, all infrasound arrays have an irregular geometry. Due to practical considerations, some do not adhere to the triangular configuration depicted above.

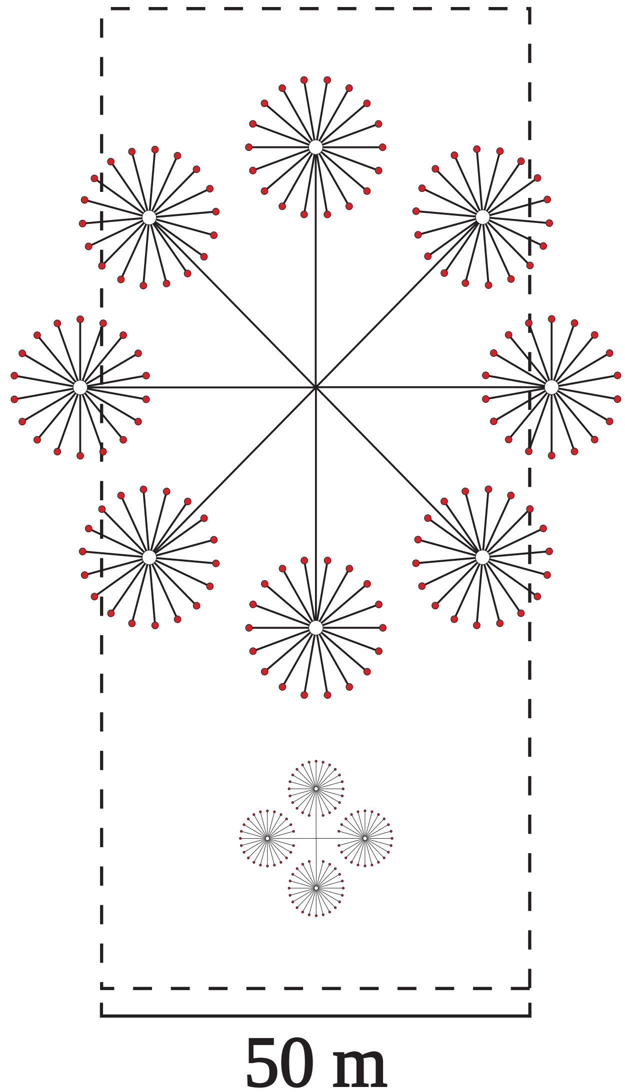

Figure 3. Noise reducing space filters span 18 to 70 meters. Low impedance inlets to the space filters are located at the end of solid pipes and are represented by the red dots in this figure. An NFL football playing surface is plotted to scale (dashed box).

Significant Remote Detections

There are myriad infrasound sources including natural ones such as atmospheric turbulence, bolides, aurora, earthquakes, volcanic eruptions, microbaroms from ocean storms, mountain associated waves, avalanches and man-made ones such as supersonic aircraft or rockets, industrial or nuclear explosions. Recent detections using the portion of the network that is now operating include the explosion of a large meteor that occurred on April 23, 2001 between Hawaii and California, USA (Figures 4 and 5). The explosion was detected at a range of 11,000 km by the infrasound array in southern Germany. IMS infrasound arrays in California, Hawaii and Alaska tracked the tropical storm "Barbara" over the Pa-

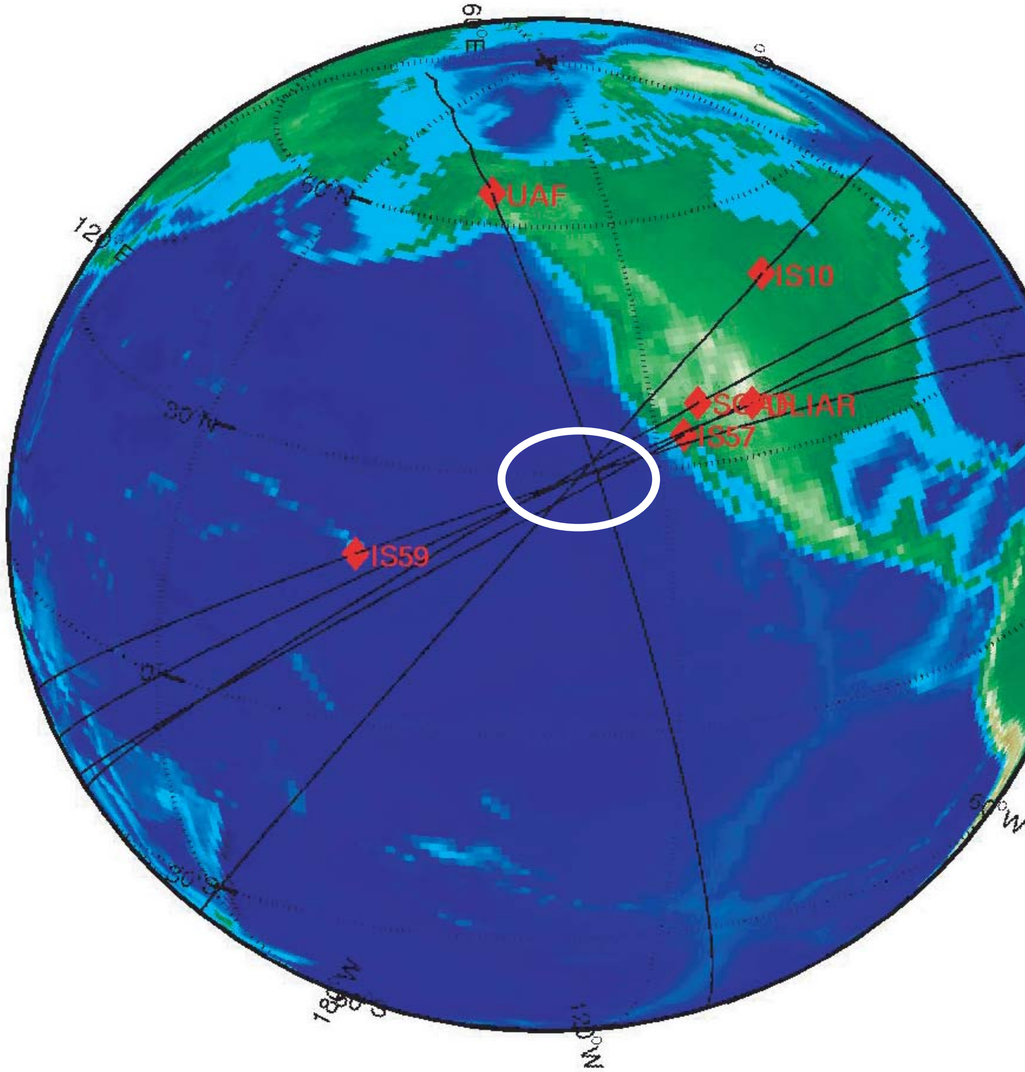

Figure 4: One significant detection by several of the new arrays in infrasound network has been identified as a large bolide which detonated at an altitude of ~ 28 km between Hawaii and southern California on April 23, 2001. This figure is from Garces et al. (2001).

cific in late June, 2001.

Current Research Issues

Although the use of low-frequency acoustic energy in the atmosphere for nuclear treaty monitoring was studied intensely in the 1950's and 1960's, the Limited Test-Ban Treaty (LTBT), which pushed nuclear testing underground, almost terminated research in infrasound. A near-hiatus in infrasound research spanned the interval from the early 1970's to the recent Comprehensive Nuclear-Test-Ban Treaty. Today, the problem of nuclear monitoring is truly global and requires that we monitor all environments for nuclear testing at all yields. The new treaty spurred development of the IMS. Given

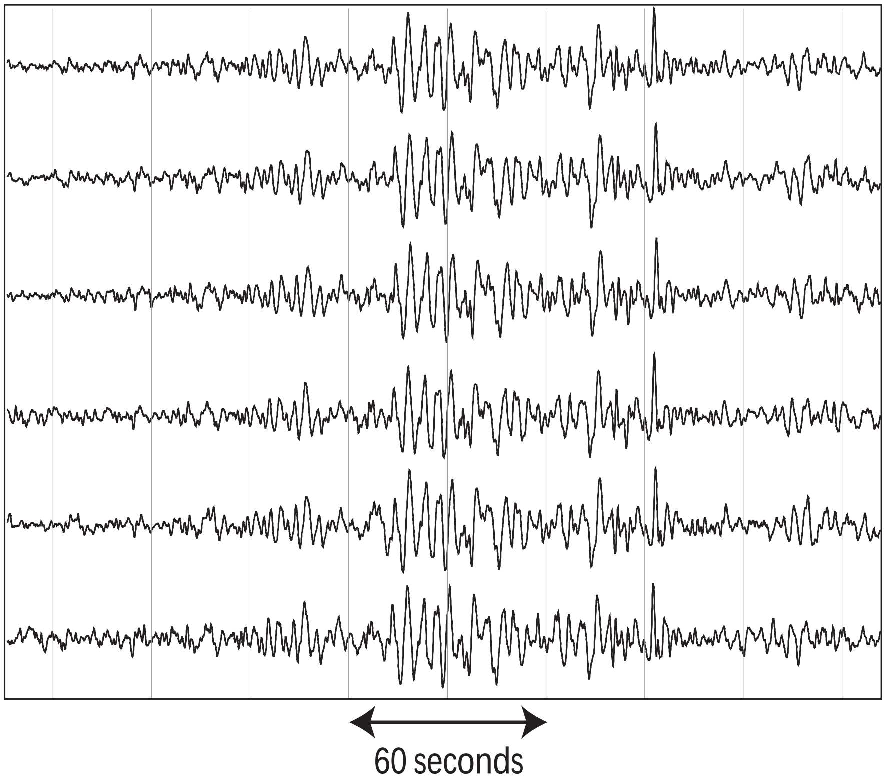

Figure 5. The recordings made by the California array are highly coherent. The explosion occurred ~ 1,800 km from the California array. The event was detected at a range of ~ 11,000 km by an array in Germany

the lengthy gap in interest in infrasound, more research on several issues in atmospheric acoustics is required for us to take full advantage of this new asset.

The problems under investigation are fundamental:

Source Physics: The essential problem the infrasound nuclear monitoring community faces is how to use remote detections by a small subset of stations in the global network to unravel the physics underlying the source of the recorded signals. From a monitoring perspective, we seek convincing evidence from the infrasound data that the event was explosive and not natural. Once a nuclear test can be ruled out, the monitoring job is finished and the detection becomes of purely scientific interest. The most important source parameters we seek are the source geographic location, elevation and duration. An impulsive event located near Earth's surface in a remote area would have to be investigated thoroughly using all available monitoring technologies. There are relatively few impulsive natural acoustic sources. Prominent examples are bolides and volcanoes.

Propagation: The character of acoustic waves is critically dependent on the velocity structure of the atmosphere between the source and the receiver. Unraveling the physics of an acoustic source using the character of the recorded signals thus requires an atmospheric model, and knowledge of how sound would propagate through that model. Empirical reference atmospheric models such as CIRA-84 and HWM-93 can be used to guide the simulations. Improved models are currently under development at the US Naval Research Laboratory. Various acoustic propagation models are used to simulate the transmission of sound waves through the empirical models. These include ray theory, normal modes and a continuous wave two-dimensional parabolic equation (PE) method. Recent detections of eruptions at Mt Etna by infrasound arrays in northern Europe did not point to the known source location and testify to the need for further research on both problems.

Noise Reduction: An essential component of each element at a typical infrasound array is the spatial noise reducing filter. Noise from atmospheric turbulence spans the entire frequency band of interest to the nuclear monitoring community (from 0.05 to 1.0 Hz). While infrasonic signals are known to be coherent at spatial scales of 10's to 100's of meters, infrasonic noise that results from atmospheric turbulence near the recording site is incoherent at spacings of 10's of meters or less. Since Daniels' pioneering work on noise reduction in the 1940s and 1950s, it has been customary to increase signal-to-noise levels by summing both signal and noise across an area surrounding the sensor. How SNR can be improved across a broad frequency band while minimizing distortion of the signal is a subject of active research. A new fiber optic sensor developed at the University of California, San Diego, has been shown to provide substantially more effective noise reduction at frequencies above 1 Hz.
Other noise reducing systems under consideration are spatially compact wind screens, other layouts of inlets that will permit integration of pressure variations at the speed of sound.

Conclusions

We have an unprecedented opportunity to monitor natural and man-made activity in the atmosphere on a global scale. Future success will depend on continued research into the physics underlying the generation of infrasonic acoustic energy in the atmosphere, propagation of the energy through an unsteady atmosphere, and clear reception of the signals despite competing signals from myriad other sources.

Acknowledgments

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References

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