INFRASOUND MONITORING OF ATMOSPHERIC EVENTS

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ABSTRACT

In the second half of the twentieth century there was an intense international effort to establish a global seismic observing system that could reveal the Earth's inner structure and reduce hazards posed by earthquakes. The recent addition of International Monitoring System (IMS) infrasound stations around the globe to complement existing arrays provides an opportunity to perceive with unprecedented fidelity energetic events that take place in our atmosphere as well as dynamic processes in the atmospheric shell that we inhabit. An update on the status of the United States and international infrasound stations will be given. In addition to an increasing number of stations, the quality of stations is also improving with the adoption of modern electronics and large spatial wind filters. This sometimes complicates the comparison of new data with data collected in past decades. Empirical relations developed based upon less capable stations must now be revalidated or modified if required. Some examples will be given. Much of the data is going to a few centralized locations where researchers interested in treaty monitoring, source physics, or propagation can access these well-documented high quality data. Natural infrasonic signals are known to be generated by meteors, volcanic eruptions, earthquakes, landslides, avalanches, glacier calvings, hurricanes, tornadoes, auroral storms, thunderstorms, sprites, littoral processes, and ocean wave fields. A host of human activities add to infrasound in the environment. For the treaty monitoring community these sources represent potential false alarms that severely complicate interpretation of infrasound data. A few examples of alternative uses of the infrasound data will be included. From a purely scientific point of view, infrasound from these sources will provide the basis for better physical modeling and understanding of processes not readily observable by other means. Most infrasound signals recorded by the expanding global system of stations are unexplained. Many of these unexplained events are, no doubt, the result of local or regional human activity but there remains the possibility that this large network will detect events from sources not yet envisioned. Several stations in the expanding infrasound array are co-located with seismic stations providing a new opportunity for data fusion.

OBJECTIVES

This paper describes the current status of the United States infrasound stations that are part of the International Monitoring System. In addition, some signals recorded at these stations will be summarized.

RESEARCH ACCOMPLISHED

The U. S. has responsibility for eight infrasound stations that are to be a part of the IMS. Those stations are:

- I-53US Fairbanks, AK
- I-54US Palmer Station, Ant.
- I-55US Windless Bight, Ant.
- I-56US Newport, WA
- I-57US Pinon Flat, CA
- I-58US Midway Islands
- I-59US Hawaii, HI
- I-60US Wake Island

In addition, the U. S. infrasound team has recently installed I-52GB at Diego Garcia. As these stations are installed, recorded signals are analyzed to gain a better insight into regional noise and false alarms. Many of the false alarms are of scientific interest for reasons unrelated to treaty monitoring.

Fairbanks, AK

The Fairbanks station is an eight-element, outer pentagon, inner triangle array. Each element has a 96 port low impedance pipe noise reducing systems with approximately 1.0 km spacing of the outer elements and 100 meter spacing of the inner elements, from the center of the array. The array is located near the University of Alaska at Fairbanks. Installation of the equipment was completed in early December 2002. Data has been transmitted to the Center for Monitoring Research (now SMDC Monitoring Research) and the IMS since that time.

Figure 1. View of I53 at Fairbanks, AK

The trees and surrounding mountains provide a relatively low wind noise environment so it was a surprise to note that when the array first began to provide data, low frequency signals historically associated with wind flow over mountains (mountain associated waves) and waves generated by aurora were not observed. The problem was traced to the phase response of the Chaparral 5.0 sensors. Changing the leak tube at the backside of the capacitance transducer corrected the problem. The station is now providing low frequency signals of unprecedented fidelity allowing for the study of pulsating aurora.

Palmer Station, Antarctica

The plan is to build a four to eight element array with spacing as allowed by the small islands in the bay.

Figure 2. Unloading equipment during the site survey at Palmer station

Windless Bight, Antarctica

The station consists of an eight-element outer pentagon, inner triangle array each with a 96 drilled matched impedance port pipe noise reduction system with approximately 1.0 km spacing of the outer five elements and 100 meter spacing of the inner elements. The station was installed in February 2001 and has been transmitting data continuously since then. The primary problem with this station has been to get data out through the restricted bandwidth available to the National Science Foundation (NSF).

Figure 3. Photo of the infrasound station at Windless Bight with Mt. Erebus in the background.

Windless Bight derives its name from the absence of wind during most of the season. The absence of wind provides a very low noise floor allowing the installation to take full advantage of the very large dynamic range and noise floor of the Chaparral 5.0 microbaragraph. Mt. Erebus seen in the background of the picture above provides frequent signals to allow for the study of volcanoes and to verify system performance.

Newport, WA

I56US is a four-element array with approximately 1 km spacing. The array was installed in August of 2002 with connection to Vienna in February 2003. The station is located in and near national forest land protected from wind by a very well developed forest. This station has not been transmitting data long enough to determine regional noise sources.

Figure 4. Certification visit at Newport. Note mature forest in background and wind noise filter inlets in foreground.

Pinon Flat, CA

The configuration at Pinon Flat is an eight-element array with 0.15-2 km spacing, one triangle inside a large one. The station has been certified since August 2002. Located in the mountains above Palm Springs, this station is often subject to significant winds. Those winds coupled with very sparse foliage give rise to high wind noise much of the time. For this reason Pinon has been used extensively to test new wind noise reduction approaches. Results of those tests have been reported separately.

Midway Islands

The configuration planned for Midway Islands is an eight-element array with 0.15-2 km spacing. Current plans are to install this station starting in June of 2004.

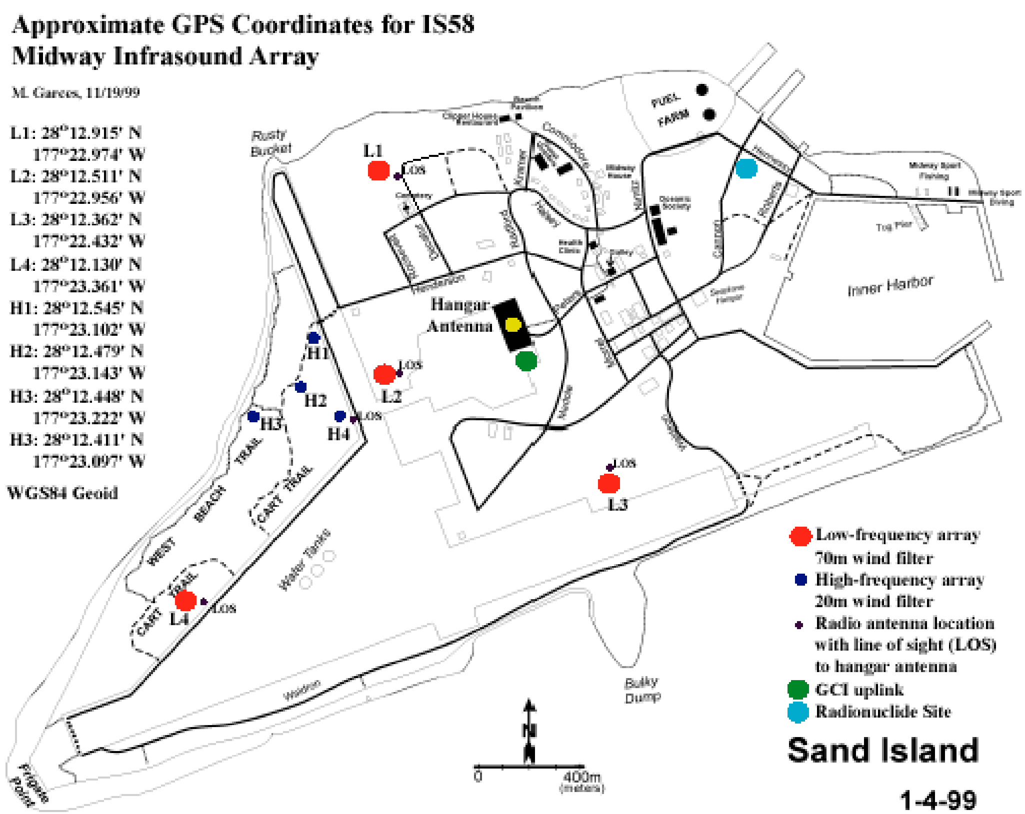

Figure 5. Midway Islands showing planned infrasound array.

Figure 6. Midway Islands is home to the endangered Albatross shown here. Plans for the installation must protect the birds and their environment.

Hawaii

The station near Kona, Hawaii was the first U. S. IMS infrasound station installed and certified (December 2001). The station is installed in an old dense forest on the leeward side of the island. Most of the time there is little or no wind on that side of the island giving rise to a very quiet station. Since the beginning of operations, substantial effort has gone into the characterization of the ambient sound field (Garces and Hetzer, 2002). Most recently, data recorded at this station has been used to better understand microbaroms, which are a major source of background noise in the 0.1 to 0.3 Hz band of the acoustic spectrum.

Wake Island

The Wake Island station is now under construction by Southern Methodist University. The plan is to use an eight-element array with approximate 1 km maximum separation. The installation should be complete by the end of the year.

Figure 7. View towards the Wake Island infrasound station.

The shortage of land, which stays dry, and the lack of foliage were instrumental in the design and location of the array.

Figure 8. Foliage available on Wake Island.

Data Exploitation at I59US

Microbaroms provide a continuous source of infrasound over the entire globe in the frequency range near 0.2 Hz. Automatic detection of nuclear explosions must exclude these continuous signals from consideration and analysis of data should exclude these signals without rejecting information about events of interest. The fact that microbaroms are almost always present might prove useful for infrasound tomography of the atmosphere.

Microbaroms are believed to be generated by the nonlinear interaction of ocean waves (Kibblewhite and Wu, 1996). The theory for predicting the frequency and magnitude of microbaroms (Arendt and Fritz, 2000) has been developed and tested, at least for a few cases (Garces *et al*, 2002b and this issue). With the installation of the infrasound array in Hawaii, data is now available over an extended period of time. In addition, sophisticated models of wave motion in the oceans such as shown in Figure 9 provide the input required to predict the location and magnitude of microbaroms. With that input, the global pressure field as a function of frequency can be computed and cannot be compared to measurements.

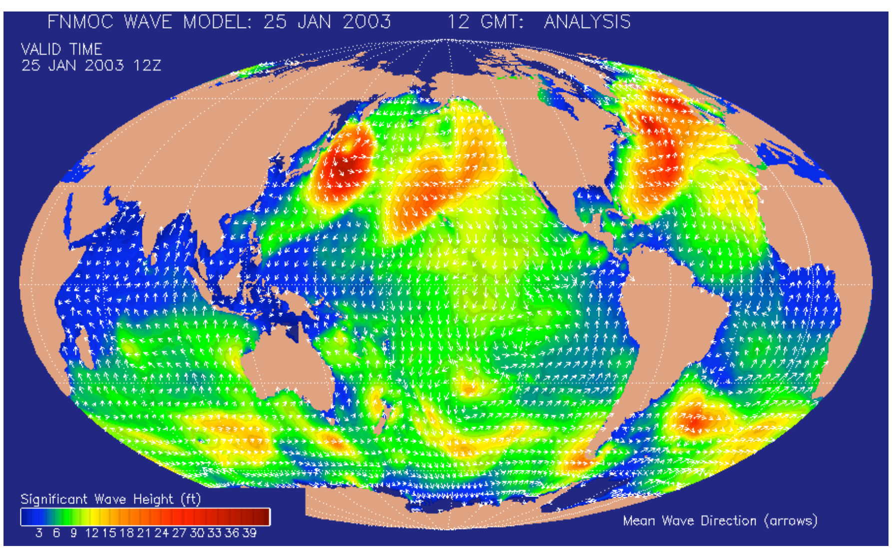

Figure 9. Calculation of wave motion globally.

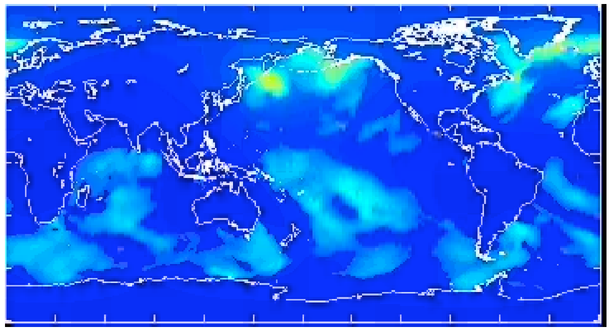

Figure 10. Predicted pressure field at a fixed frequency from microbaroms generated by the wave model in Figure 9.

In the coming months, as more stations come on line to allow better location of the microbaroms, these calculations will be compared to the experimental observations to determine how accurately the microbaroms can be located from independent measurements and removed from event lists to reduce false alarms.

Ground-Truth Data Base

The sensitive and high fidelity infrasound arrays that are a part of the International Monitoring System require data from similar arrays to build a database of events that will allow an analyst or automatic detection system to identify events of interest. Since new IMS stations have been coming into operation, events of different types have been identified from observations other than infrasound. The infrasound recordings from stations in the area have been analyzed, and the part of the signal associated with the known event have been cataloged. Over time, this database will include regional as well as global sources. The events that have been added to the SMDC Monitoring Research database are shown in Figure 11.

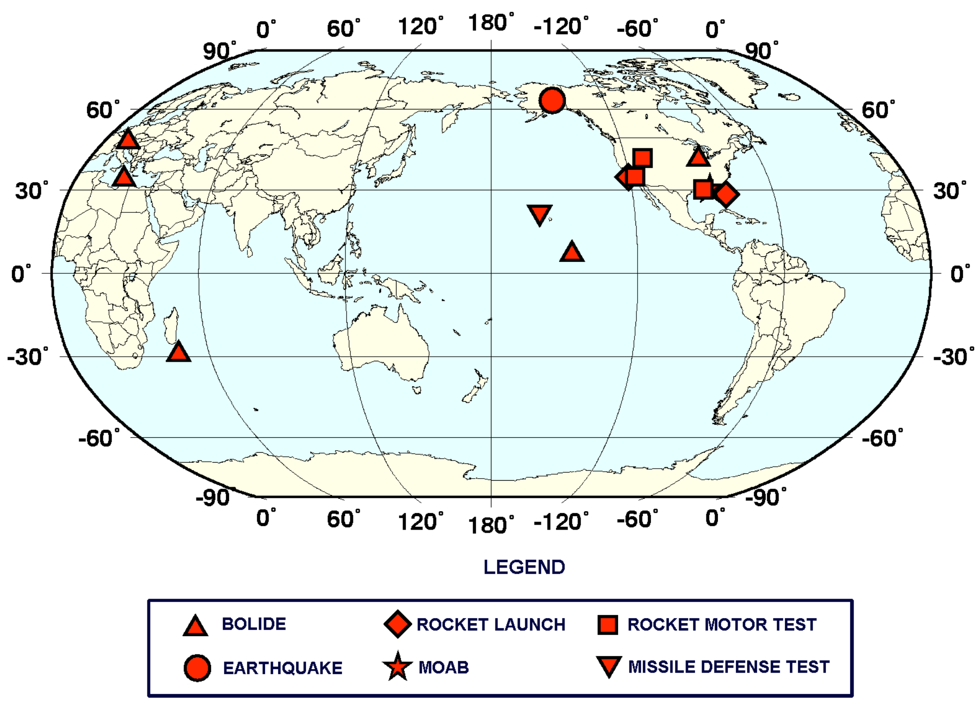

Figure 11. Recent infrasound events collected at SMDC Monitoring Research

Table 1. Ground Truth Data Base Additions

Event Type	Event Information	Detecting Stations						
Bolide	March9_2002	I57US	IS10	I59US	PDIAR	SGAR		
	April6_2002	IS26	DIA					
	June6_2002	IS26						
	July25_2002	I33MG						
	March28_2003	I10CA	Blossom Point					
Shuttle	Columbia_breakup	TXIAR	SGAR	I10CA	PDIAR			
Earthquake	November3_02	I53US	SGAR					
Hawaii Missile Defense Tests	January27_2002	I59US						
	June14_2002	I59US						
	November21_2002	I59US						
Bomb Drop	MOAB	Null observation						
Rocket Launches	November20_2002 (Cape Canaveral)	IS10	TXIAR					
	October14_2002 (Vandenberg)							
Rocket Motor Test	Thiokol (January23_2003)	NVIAR	DLIAR	I57US	TXIAR	I56US		
Chemical Explosion	Watusi (September28_2002)	NTS	NVIAR	SGAR	PDIAR	IS10	DLIAR	LSAR
	Billy-Berclau (March27_2003)	DBN	IS26					

CONCLUSIONS AND RECOMMENDATIONS

The growing number of high quality infrasound stations around the globe provide a unique opportunity to explore the capabilities of this technology for nuclear test monitoring, signal to noise improvement, development of useful automatic detection approaches, and document naturally occurring and man made sources. This global network of stations will also allow scientific applications, potential for early warning of natural events (volcano plume warning for example), and verification of future treaties.

ACKNOWLEDGEMENTS

Dr. Joydeep Bhattacharyya as part of the SMDC Monitoring Research provided most of the ground-truth information along with Figure 11. More information on accessing this database can be obtained from Dr. Bhattacharyya.

REFERENCES

Arendt, S. and D. Fritts (2000), Acoustic Radiation by Ocean Surface Waves, *J. Fluid Mech*, 415, 1-21.

Garces, M. and C. Hetzer, Evaluation of Infrasonic Detection Algorithms, *Proceedings from the 24th Seismic Research Review - Nuclear Explosion Monitoring: Innovation and Integration*, Ponte Vedra, FL, 17-19 September 2002a, LA-UR-02-5048.

Garces, M., C. Hetzer, S. Businger, and M. Willis, Modeling of Microbarom Signals in the Pacific, *Proceedings from the 24th Seismic Research Review - Nuclear Explosion Monitoring: Innovation and Integration*, Ponte Vedra, FL, 17-19 September 2002b, LA-UR-02-5048.

Kibblewhite, A. and Cheng Y. Wu (1996), Wave Interactions as a Seismo-Acoustic Source, *Lecture Notes in Earth Sciences*, Springer-Verlag, Berlin.