ADVANCES IN INFRASOUND TECHNOLOGY WITH APPLICATION TO NUCLEAR EXPLOSION MONITORING

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ABSTRACT

The principal goal of this investigation is to develop new techniques that will enhance the use of infrasound for the detection, location, and discrimination of atmospheric nuclear explosions at stations in the global infrasound monitoring network. This work is focused primarily on two important problems. The first is concerned with limitations imposed on array detection of explosion-generated infrasound by the loss of signal correlation between elements in large sparse arrays, and the second encompasses the long-standing problem in the field of infrasound monitoring of unacceptably high levels of background noise caused by wind-generated turbulence. This study is also concerned with the identification and classification of the fundamental physical processes that result in background noise at all frequencies at infrasound monitoring stations. The results of this study are based on a thorough analysis of a large infrasound database comprising six years of archived data from IS07 Warramunga in northern Australia, three years of archived data from IS05 Hobart in Tasmania, a one-year archive of data from IS04 Shannon in southwest Australia, shorter periods of selected data from other International Monitoring System (IMS) infrasound stations and data collected during a number of field experiments in Australia using a portable infrasonic array.

The study of the spatial correlation properties of infrasound signals has shown that a low degree of signal correlation can seriously limit the reliable detection of infrasound generated by distant explosions in the primary monitoring passband (0.4 to 1.5 Hz) at a number of sparse IMS arrays with widely separated array elements. We have, however, found that the currently accepted parameters that are used in the standard theoretical description of infrasound signal correlation lead to predictions for signal correlation that are less than the observed values. The model parameters have therefore been refined to give a theoretical description that is in better agreement with observations. We have also extended the calculations of the predicted variation of array-averaged signal correlation as a function of azimuth and frequency to a number of typical IMS array configurations with a large number of elements. A comparison of these results with observations suggests that the performance of some monitoring stations with non-standard array configurations may be limited at higher frequencies by signal correlation problems.

Considerable progress has been made on the development of a noise-reducing system that can strongly attenuate, and in some cases, effectively eliminate wind-generated background noise in the monitoring passband at infrasound monitoring stations. Wind-generated noise is a serious problem, especially during the daytime, at many infrasound stations. Work on wind-noise reduction in the past has been primarily concerned with the development of improved wind-noise-reducing pipe-array systems. It is clear that further refinements to these pipe-array systems will not lead to a significant improvement in wind-noise-reducing capability since the size of these arrays and the number of inlet ports have reached practical limitations. We have therefore developed a new type of wind-noise-reducing system that mechanically attenuates and transforms turbulent eddies that generate noise in the primary monitoring passband. The design and performance of a wide variety of these turbulence-reducing systems is given in this paper along with recommendations for the use of these systems. The latest version of this system has proven to be very effective. Indeed, tests of this system have shown that this system almost completely eliminates wind noise in the primary monitoring passband under typical daytime wind conditions at an unsheltered semi-desert site. In addition, we have found, in some circumstances, that these turbulence-reducing enclosures may be used with only a single inlet port as effective stand-alone wind-noise reducing systems that do not require a pipe array.

OBJECTIVES

The primary objectives of this research project are to identify problems with the detection of atmospheric nuclear explosions at infrasound monitoring stations and to develop techniques using infrasound technology that will enhance detection capability for regional and distant nuclear explosions in the atmosphere.

This project is concerned with an investigation of the monitoring capability of infrasound stations in the global network with special attention devoted to the detection of explosions that occur over the vast open ocean areas in the Pacific and Indian Oceans. The monitoring stations that surround these remote areas need to have good detection capability for explosions at distances of up to at least 4500 km in order to achieve reliable two-station detection capability for 1kiloton explosions.

RESEARCH ACCOMPLISHED

Introduction

Much of the research in this project is based on a survey of signal detection capability and background noise characteristics of certified Australian IMS monitoring stations (see Figure 1). This survey has highlighted three important problems that may limit the performance of stations in the global monitoring network:

a) Distant explosions may be detectable only as longer period signals (Christie et al., 2005a) when wave propagation is restricted to a thermospheric waveguide. It is therefore essential to ensure that routine data analysis procedures include a search for longer period signal components at frequencies below the microbarom passband. Problems associated with the decay of higher frequency signal components at a given station will depend on the location and distance to the source and the seasonal waveguide characteristics between the source and the monitoring array.

b) The optimum monitoring passband (Christie et al. 2005b; 2006) for stratospheric arrivals from regional and distant explosions is generally limited to a frequency range extending from about 0.4 Hz to slightly above 1.0 Hz. The lower frequency limit depends on the intensity of microbarom infrasonic signals and the high frequency limit is determined by both spatial aliasing of higher frequency signals and problems with signal coherence between array elements. The detection of higher frequency signals depends critically on the design of the array configuration. Spatial aliasing problems can be eliminated by using an eight- or nine-element array configured in the form of a logarithmic spiral or in the form of a larger aperture pentagon array with a smaller aperture triangular sub-array (or centered triangle sub-array) located at the center of the main array. Signal coherence between array elements at higher frequencies also depends on the array configuration. Results obtained to date have shown that detection capability for regional and distant explosions at existing monitoring stations with a small number of array elements and a large aperture will be marginal due to the low degree of signal coherence between array elements. The study of signal coherence is proving to be a fairly complex subject. The goal of this part of the project is to provide an accurate signal coherence model that can be used to optimize the array design at infrasound monitoring stations.

c) Wind-generated background noise is by far the most important technical issue in the field of infrasonic monitoring. More than half of the stations in the global monitoring network are subject at times to unacceptably high levels of wind-generated background noise. It is clear that the development of a system that will significantly reduce and possibly eliminate wind-generated noise at infrasound monitoring stations would greatly enhance the performance of the IMS infrasound monitoring network and would lower the global monitoring threshold. The use of an effective and reliable wind-noise suppressing system at IMS infrasound stations would probably result in three-station detection capability for 1 kiloton explosions at most stations in the global network. Global three-station detection capability is desirable since this would significantly improve the reliability of the network and would greatly enhance location capability. Results from the new type of wind-noise-reducing system described in this paper suggest that the use of this noise-reducing-system, either as a stand alone system or in conjunction with existing pipe arrays, can substantially reduce wind-noise levels in the primary monitoring passband. In view of the overall importance of the wind-noise problem to the field of infrasound monitoring, a major part of this paper will be devoted to a description of the design and evaluation of the new type of wind-noise-reducing system.

Spatial Correlation of Explosion-Generated Infrasonic Signals at IMS Infrasound Monitoring Stations

The array configuration at the three certified IMS infrasound stations on Australian territory, IS04 Shannon in the southwest corner of Australia, IS05 Hobart near the east coast of Tasmania and IS07 Warramunga in the Northern Territory, are compared in Figure 1. The aperture of each of the arrays illustrated in Figure 1 is approximately the same and the configuration at each array includes both a large aperture main array and a small aperture sub-array. However, the array configurations at these stations differ substantially. The small aperture sub-array at IS07 is located at the center of the larger aperture main array. In contrast, the small aperture sub-arrays at IS04 and IS05 are located outside the area of the larger aperture array. The unusual array configurations at IS04 and IS05 were determined by the available land area and problems with the supply of power to the array elements. The design of the array configurations at IS04 and IS05 is not ideal and signal correlation problems could lead to reduced detection capability at higher frequencies. This possibility is discussed briefly below. The array responses of all of the arrays shown in Figure 1 exhibit reasonably good side-lobe-suppression characteristics. Spatial aliasing of signals may be a problem at higher frequencies for low signal-to-noise ratios, but this problem can be minimized using the technique described by Kennett et al. (2003).

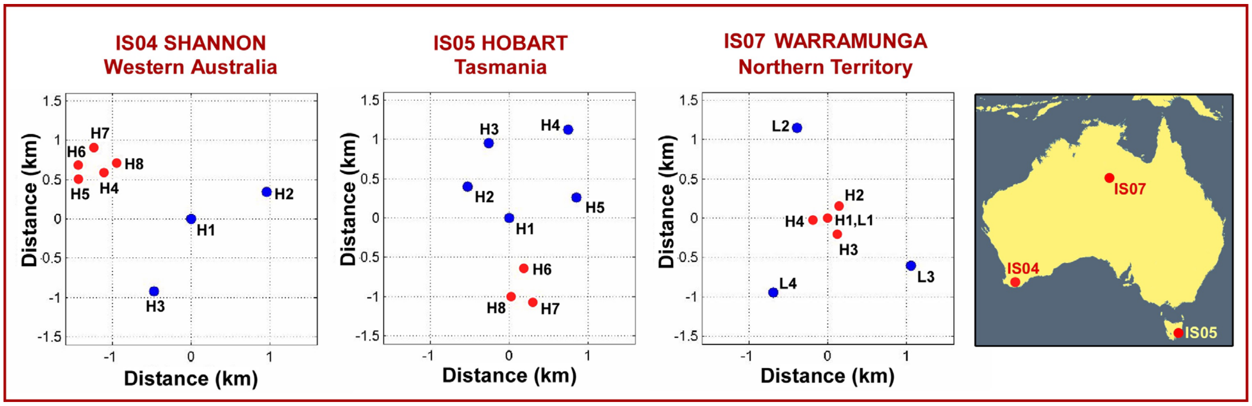

Figure 1. Comparison of the array configurations at IS04 Shannon, IS05 Hobart and IS07 Warramunga. Each array includes a small-aperture sub-array.

A large number of open-cut mines are located throughout the Australian mainland and in Papua New Guinea to the north of the Australian continent. Waveform data recorded at IS04, IS05, IS07 and temporary portable array stations from a large number of explosions at these mines have been assembled into a database for the investigation of the spatial coherence properties of explosion-generated infrasonic waves. This data set has been supplemented by waveform data from a number of volcanic eruptions, bolide explosions, and test chemical explosions. The data set includes signals generated by explosions located at distances ranging from a few hundred kilometers to more than 3000 kilometers. These signals have been detected at a wide range of azimuths and during all seasons of the year.

The technique that has been used to determine the coherence properties of infrasonic signals has been described in Christie et al. (2006). The basic theoretical framework for a signal coherence model is given in Gossard (1969), Gossard and Sailors (1970) and Mack and Flinn (1971) (see also Gossard and Hooke (1975). We have adopted the model proposed by Mack and Flinn since this simple model captures the essential physics of the problem and the model parameters can be easily determined from observations. Mack and Flinn (1971) derived an expression for signal coherence that provides a good fit to the observed coherence of long period infrasonic signals generated by large explosions detected at great distances at a large aperture infrasonic array. Since signal correlation, C, between two sensors separated by vector $\mathbf{r}$ at a specified frequency, is given by the square root of the squared coherency (Blandford, 2000), the expression for signal coherence in Mack and Flinn can be rewritten for convenience as:

$$C(\mathbf{r},T) = \sqrt{\gamma^2(\mathbf{r},T)} = \sqrt{\left|\frac{\sin\left(2\pi x \sin(\Delta\theta)/cT\right)}{2\pi x \sin(\Delta\theta)/cT}\right|^2 \cdot \left|\frac{\sin\left(2\pi y \Delta c/(cT(c+\Delta c)\right)}{2\pi y \Delta c/(cT(c+\Delta c)}\right|^2} \quad , \qquad (1)$$

where T is period, c is the mean phase velocity, x and y are the components of the vector separation r, $\pm\Delta c$ represents the observed loss of signal coherence due to a small variation in wave velocity along the direction of wave propagation and $\pm\Delta\theta$ is a measure of the observed loss of coherence along the wavefront due to a small variation in wave azimuth. Blandford (1997) extrapolated the long-period results of Mack and Flinn to higher frequencies and found a new set of model parameters, Δc = 15 m/s and $\Delta\theta$ = 5º, that provides a fairly good fit to observations at frequencies above 0.1 Hz. Additional work on the subject has been reported by Armstrong (1998), Blandford (2000, 2004), McCormack (2002) and Christie et al. (2005a, b; 2006).

The comparison of signal correlation observations with theory is often made by attempting to find observed values of signal correlation for sensors aligned parallel and perpendicular to the wavefront and comparing these results with the curves described by expression (1) with y = 0 (sensors aligned parallel to the wavefront) and x = 0 (sensors aligned normal to the wavefront) for various frequencies and sensor separation distances. This procedure may be subject to error when the comparison is based on data from a fixed array with a small number of array elements where few, if any, array element pairs are aligned normal and perpendicular to the wave propagation direction. We have therefore adopted a new procedure in which we calculate the array-averaged correlation coefficient as defined by the Mack and Flinn model as a function of azimuth and frequency and compare this directly with observations. This procedure includes a contribution from all array element pairs and can be used with any array configuration and any source azimuth. A brief description of the calculation of the polar distribution of the array-averaged correlation coefficient is given in Christie et al. (2006). The calculation is carried out by computing the predicted angular variation of the signal correlation as defined by (1) for each sensor pair in an array in geographical coordinates and then averaging the results at each azimuth over all sensor pairs. The resulting polar distribution of the array-averaged correlation coefficient provides a unique characteristic of the array configuration that can be used to enhance array design. The azimuthal distribution of signal correlation given by expression (1) is highly anisotropic at higher frequencies. As a consequence, the polar distribution of the array-averaged correlation coefficient may also be anisotropic and this can have a detrimental influence on the detection capability at certain azimuths for higher frequency waves.

Preliminary results that illustrate problems with the deterioration of signal coherence when the distance between array elements is large and problems with an anisotropic array-averaged correlation coefficient at higher frequencies have been given in Christie et al. (2006). The investigation of the coherence properties of infrasound signals is an ongoing project. Here, we extend the results of the calculation of the array-averaged correlation coefficient to triangular arrays with various apertures and compare the results with further observations of explosion-generated infrasonic waves recorded at IS07 Warramunga at frequencies of 0.5, 1.0, and 2.0 Hz. Three tri-partite sub-arrays at IS07 (see Figure 1) are chosen to illustrate potential signal coherence problems:

(A) A small sub-array formed by array elements H1, H2 and H3 with an aperture of about 0.3 km,

(B) A medium size sub-array formed by array elements H2, L3 and L4 with an aperture of about 1.5 km, and

(C) A large aperture array defined by array elements L2, L3 and L4 with an aperture of about 2 km.

The predicted azimuthal variation of the array-averaged correlation coefficient for each of these sub-arrays at frequencies of 0.5, 1.0, and 2.0 Hz as computed from the Mack and Flinn model with Blandford's parameters (Δc = 15 m/s and $\Delta\theta$ = 5°) are presented in Figure 2. As can be seen from these results, the array-averaged correlation coefficient is highly anisotropic at higher frequencies in the case of the larger aperture arrays. The value of the array-averaged correlation coefficient predicted for these larger arrays is also too small to allow reliable detection of signals at frequencies of 1.0 Hz or higher. The predictions indicate that good detection capability at all azimuths at frequencies of up to 2.0 Hz will only be possible in the case of the small 0.3 km aperture tri-partite array. The azimuthal distribution of the array-averaged correlation coefficient for the large 2.0-km array is also anisotropic and attenuated at a frequency of 0.5 Hz, which suggests that detection capability will be marginal at all frequencies above 0.5 Hz for sparse arrays with apertures of 2 km or more.

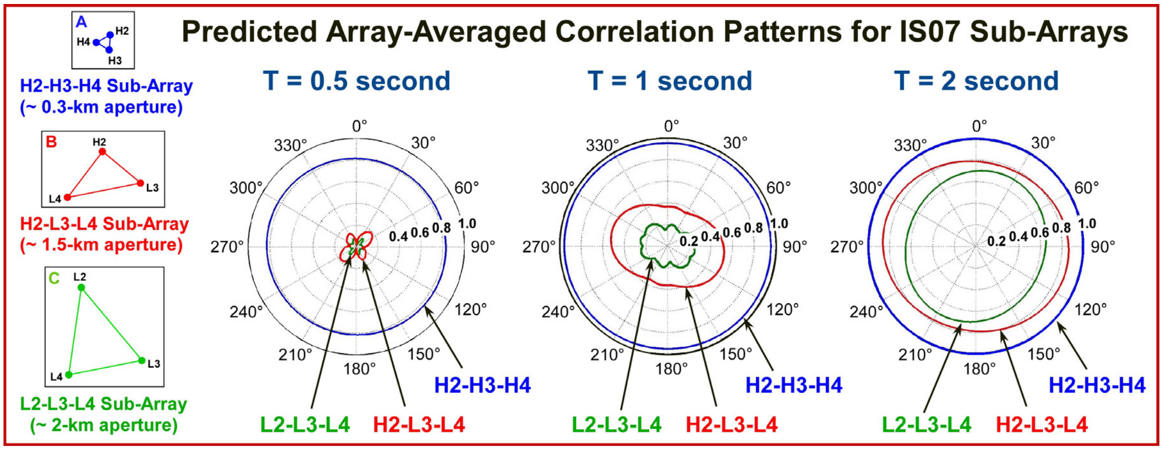

Figure 2. Predicted azimuthal variation of the array-averaged correlation coefficient for (A) a small aperture (~0.3 km) sub-array (in blue), (B) a medium aperture (~1.5 km) sub-array (in red) and (C) a large-aperture (~2 km) sub-array (in green) at IS07 Warramunga, Australia at periods of 0.5, 1.0, and 2.0 seconds. The azimuth is measured from north. The calculations are based on Δc = 15 m/s and $\Delta\theta$ = 5° as found by Blandford (1997).

Observations of array-averaged correlation coefficients obtained using the three tripartite sub-arrays at IS07 Warramunga for infrasonic waves from a variety of naturally occurring and man-made explosions are compared with the predictions of the Mack and Flinn model in Figure 3. These observations are in fairly good agreement with the model predictions. Observed signal correlation decreases rapidly with increasing frequency and with increasing array aperture in agreement with the Mack and Flinn model. The observations confirm that the degree of signal correlation of infrasound from regional and distant explosions is very low on sparse arrays with apertures of about 1 km or more at frequencies above 1 Hz. These results indicate that the detection capability of some existing IMS 4-element infrasound arrays with apertures of more than 2 km for regional and distant explosions will be marginal when automatic routine processing is carried out using detection algorithms that are based on signal correlation between array elements.

It is worth noting, however, that the theory of Mack and Flinn with model parameters Δc = 15 m/s and $\Delta\theta$ = 5º as found by Blandford (1997) predicts array-averaged correlation coefficients that are somewhat smaller than those observed, especially in the case of mining and other chemical explosions with frequencies of 0.5 and 1.0 Hz. It therefore appears that the present coherence model for infrasound signal correlation is too restrictive. The Mack and Flinn parameters, Δc and $\Delta\theta$, need to be adjusted to give a better fit to the observations. This process is underway and a preliminary estimate for a more accurate set of parameters is Δc = 14 m/s and $\Delta\theta$ = 4.5º. We emphasize that the relatively small changes to the current signal correlation model do not in any way change the essential conclusions. The monitoring capability of 4-element IMS arrays with apertures of more than 2 km for regional and distant nuclear explosions is, at best, marginal.

The results presented above for the array-averaged correlation coefficient suggest that there may be other fundamental problems with the design of an array configuration that could result in marginal detection capability. This can be illustrated by the unusual asymmetric array configurations at IS04 and IS05. An array configuration should be designed to maximize the number of array element pairs that contribute significantly to the array-averaged correlation coefficient and to ensure a symmetrical azimuthal distribution of the array-averaged correlation coefficient in the monitoring passband. In this regard, the array configurations at IS04 and IS05 are not optimum, even though they both exhibit a reasonable array response. In the case of the IS04 and IS05 arrays, the array-averaged correlation coefficient will be dominated at higher frequencies by contributions from the smaller aperture sub-array (shown in red in Figure 1). Contributions from most array element pairs formed by one element in the large array and one element in the small sub-array will be negligible. This means that the arrays at IS04 and IS05 will be dominated by a small sub-array and the overall array-averaged correlation coefficient at higher frequencies will be reduced. In addition, the asymmetry in the arrays at IS04 and IS05 will lead to anisotropy in the azimuthal distribution of the array-averaged correlation coefficient at frequencies in the primary monitoring passband.

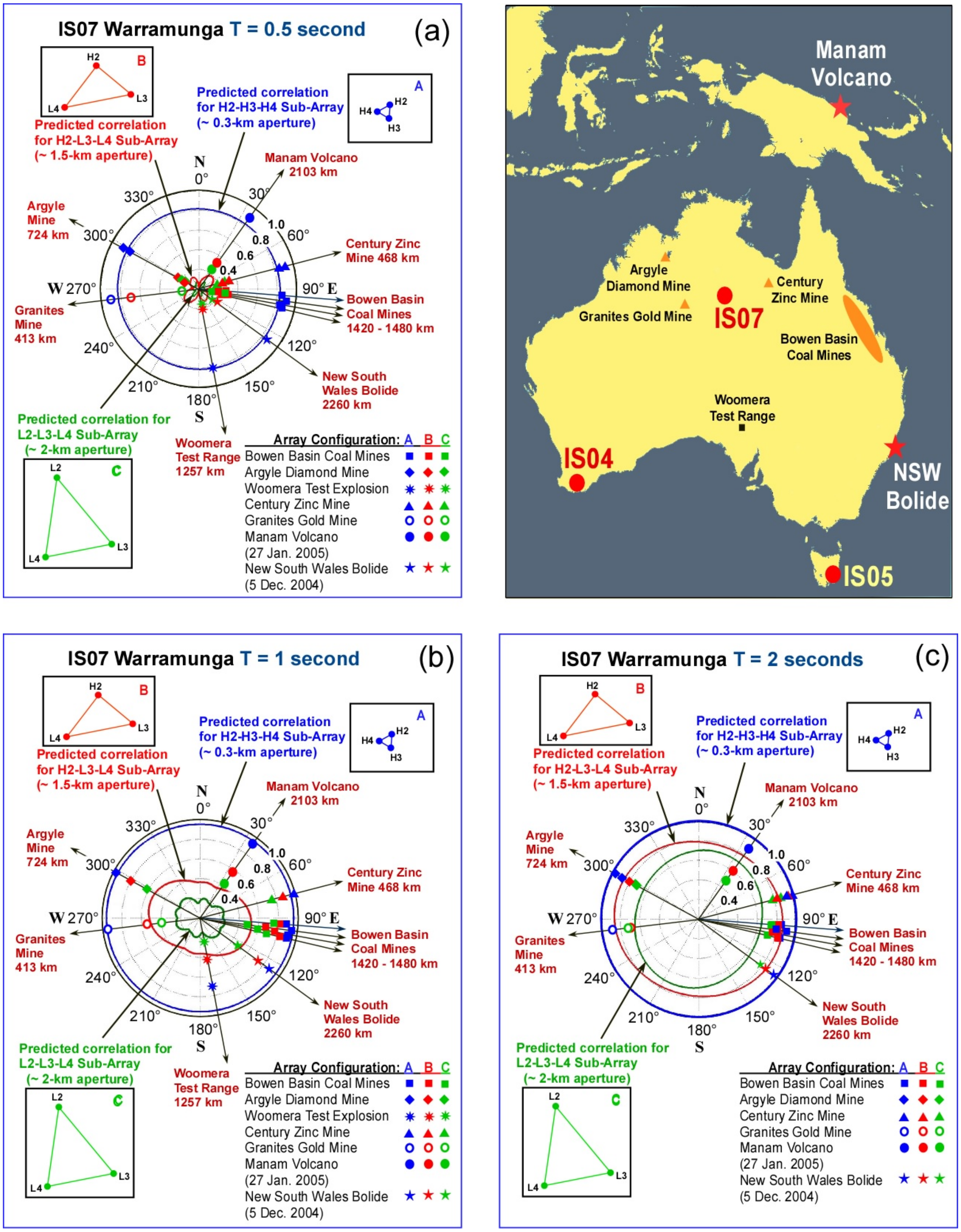

Figure 3. Comparison of theoretical and observed array-averaged correlation coefficients for infrasonic signals from regional and distant mine and other chemical explosions and distant volcanic and bolide explosions recorded on small, medium and large aperture sub-arrays at IS07 Warramunga. (A) 2.0 Hz infrasonic signals. (B) 1.0 Hz infrasonic signals. (C) 0.5 Hz infrasonic signals.

Development of a New Wind-Noise-Reducing System

Wind-generated background noise has been an exasperating problem in the field of infrasound monitoring for more than 50 years. While there has been some progress in the last 10 years in the development of improved noise-reducing systems, the improvements have been relatively small. Adaptive signal processing of data from a large number of distributed sensors at each array element has been proposed as an effective noise-reducing technique (Tamadgee et al., 2001; Bass and Shields, 2004; Shields, 2005). Tests of the small-scale wind barrier designed by L. Liszka at the Swedish Institute of Space Physics in 1972 for noise reduction at higher frequencies have been reported by ReVelle (private communication, 2000) and Hedlin and Berger, 2001. An important development has been the use described by Bedard et al. (2004) of a porous wind fence with corrugations as a means for wind noise reduction at higher frequencies in an infrasound tornado-warning system. Almost all noise-reducing systems in use at infrasound monitoring arrays are based on the spatial averaging of the micropressure fluctuations around an array element using a complex pipe array. It seems clear that further refinements to existing pipe array designs will not lead to significant improvements. Pipe arrays occupy a large area and are expensive to install. In addition, higher frequency signals are attenuated and distorted by pipe arrays and the transfer function may not be accurately known.

The infrasonic wind-noise problem can be illustrated by the noise levels at IS07 Warramunga (see Figure 4) which are similar to those found at many infrasonic monitoring stations installed in areas with relatively little protection from the ambient winds. All winds are measured at a height of 2.0 m. The ambient wind speed at IS07 is usually very low at night and high during the day. This invariably results in unacceptably high background noise levels during the daytime. The lower limit on the sensitivity of IS07 at frequencies above 1 Hz (red curve in Figure 4 for zero wind speed) is determined by the electronic noise floor of the MB2000 microbarometer (~4×10^{-7} Pa^2/Hz). We have also included for comparison power spectral density estimates of background noise recorded simultaneously at H2 in zero wind conditions using a Chaparral Physics Model 5 microbarometer (blue curve). This microbarometer has a much lower electronic noise floor than the MB2000 microbarometer.

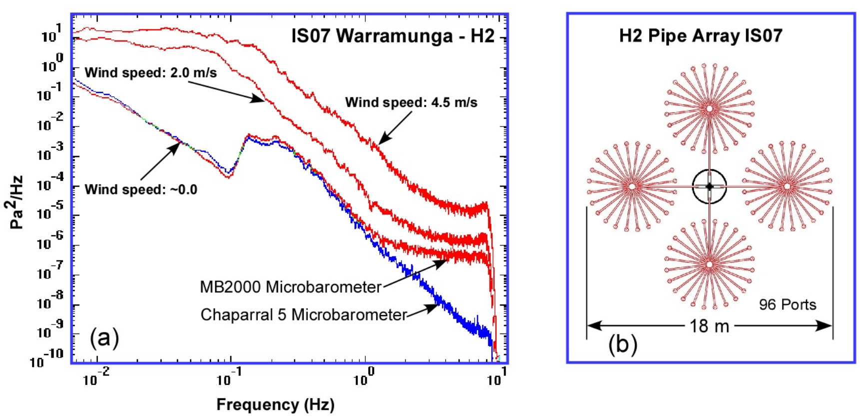

Figure 4. (a) Power spectral density of infrasonic background noise recorded at site H2 at IS07 Warramunga. Curves shown in red were recorded using the DASE MB2000 microbarometer installed at H2 with a standard CTBTO 18-m diameter rosette noise-reducing pipe array system on the input to the microbarometer. The 96-port pipe array is illustrated schematically in (b). The blue curve in (a) corresponds to data recorded simultaneously in zero wind using a Chaparral Physics Model 5 microbarometer.

The state-of-the-art pipe arrays at IS07 do not resolve the problem of high wind noise levels during the daytime. A new approach to the problem of wind-noise-reduction is required. We have therefore focused on techniques that result in the attenuation and transformation of wind-noise-generating turbulent eddies in the neighborhood of the inlet (or inlets) to the microbarometer infrasound sensor. This is achieved through the use of turbulence-reducing enclosures constructed from porous screens stretched over a rigid framework. We have constructed and tested a fairly large number of turbulence-reducing enclosures during the last nine months. All of these experiments have been carried out at IS07 Warramunga using Chaparral Physics Model 5 microbarometers for evaluation. The design of the turbulence reducing enclosures was originally based on open structures with two concentric porous walls with outward-facing inclined deep serrations on the top, which help to prevent the blocked ambient flow from folding over the walls and generating unwanted turbulence near the surface inside the structure.

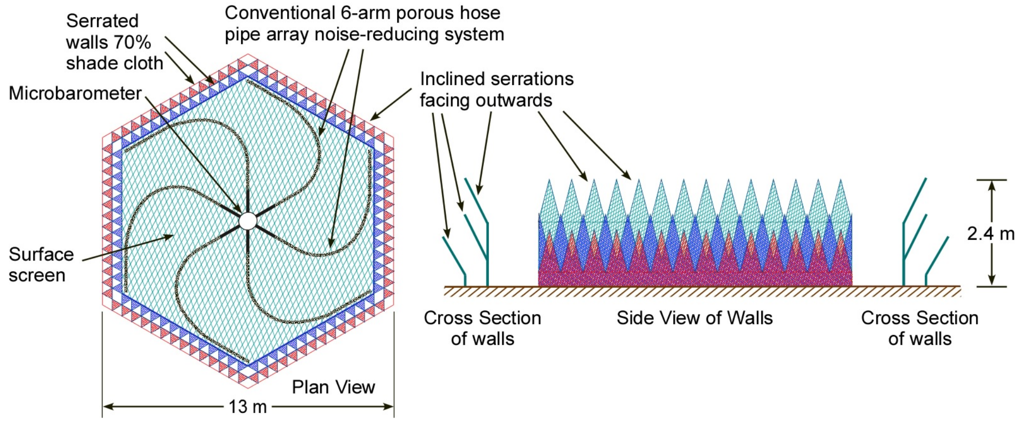

Figure 5. Schematic diagram illustrating Version 2 of the turbulence-reducing enclosure with three rows of inclined overlapping deep serrations arranged on two porous walls. The plan view also shows the layout of the conventional 6-arm porous hose pipe array system, which was used to test this noise-reducing system.

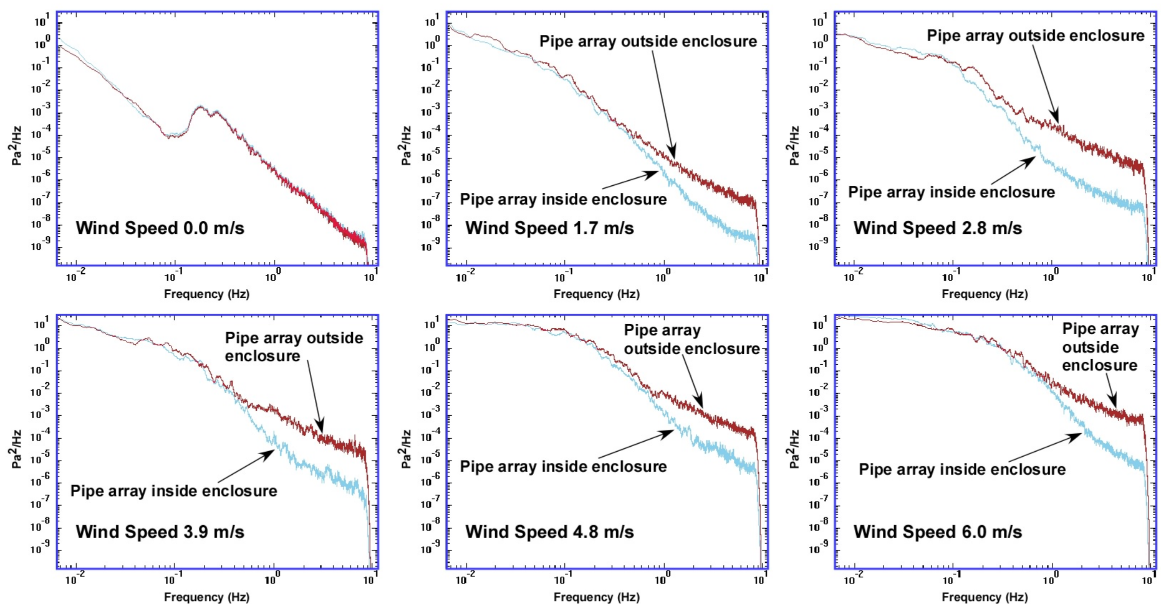

Figure 6. Comparison of power spectral density estimates of background noise for porous hose pipe array systems located inside and outside Version 2 of the turbulence-reducing enclosure for wind speeds up to 6.0 m/s.

The inner wall of the first version of the enclosure (Version 1) was 1.6-m high. The performance of this open enclosure was fairly good in modest winds, but the efficiency dropped rapidly as wind speeds increased above 3.2 m/s. A schematic diagram of the second turbulence-reducing enclosure (Version 2) with 2.4-m high inner walls is shown in Figure 5 and the results of the performance tests for this open enclosure are presented in Figure 6. These tests were carried out with identical conventional porous hose pipe arrays located inside and outside the enclosure. The performance of Version 2 of the enclosure is significantly better than the performance of Version 1. The higher walls in this case are clearly beneficial. However, the efficiency of Version 2 of the enclosure decreased rapidly in winds of more than 4.5 m/s. Versions 1 and 2 of the enclosure, when used with a conventional pipe array, provide good noise reduction in modest winds, but neither of these systems reduce wind noise to completely acceptable levels at IS07 during average daytime wind conditions. Versions 3 and 4 were constructed to test the influence of increasing the height of the walls to 3.2 m. The increased wall height did not improve the performance of these open enclosures. Tests at this point indicated that the interaction of the higher serrations on the walls with the ambient winds at a height of 3 m was generating turbulence inside the structure. We then added radial baffles inside the structure along with an inner walled enclosure in an attempt to reduce the level of turbulence inside the structure. Both of these additions were effective, but the gains in performance were relatively small. However, we found that a roof over the inner structure resulted in a dramatic decrease in noise levels at the center of the enclosure. We then decided to remove all higher serrations and to transform the enclosure into a closed structure with a lower profile. Version 5 of the enclosure (see Figure 7) was constructed with a reduced height of 2.0 m, a second smaller roofed chamber at the center for use with a single port system, radial baffles, and a screened roof over the entire structure. *Horizontal* outward-facing serrations and *downward* -inclined, outward-facing larger-scale serrations, both attached at the outer edge of the roof, were introduced to minimize the generation of turbulence on the upper edges of the structure. Test results (see Figure 8) show that Version 5 of the enclosure is a very effective noise-reducing system.

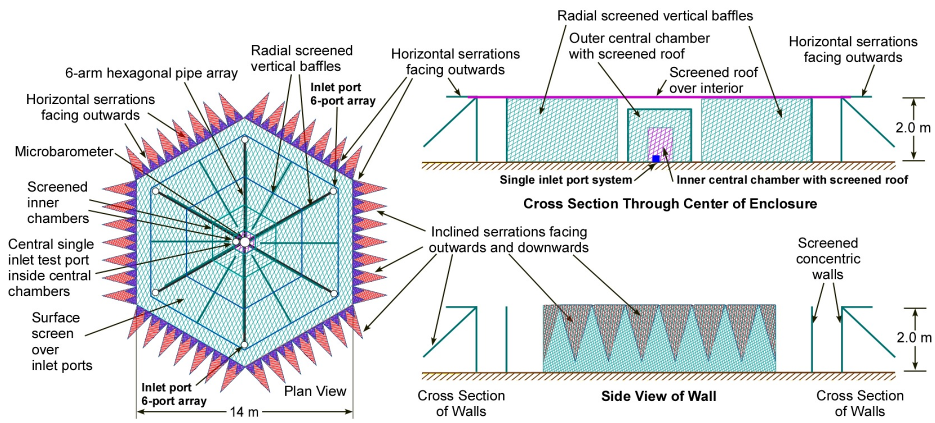

Figure 7. Schematic diagram illustrating Version 5 of the turbulence-reducing enclosure with vertical baffles, enclosed inner chambers and a screened roof over the entire interior of the structure. All higher serrations on the outer walls have been replaced by (a) horizontal outward-facing serrations and (b) larger scale outward-facing and downward-inclined serrations attached to the upper edge of the structure.

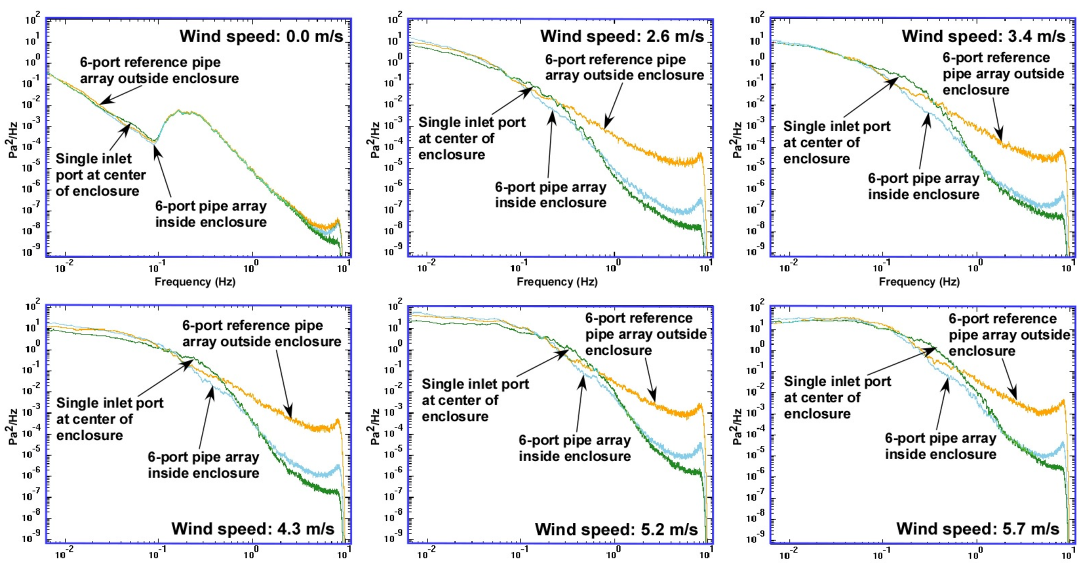

Figure 8. Comparison of power spectral density estimates of background noise recorded with identical 6-port pipe array systems located inside and outside Version 5 of the enclosure. The green curve corresponds to background noise recorded on a single inlet port system located at the center of the enclosure.

Note that the performance of Version 5 of the enclosure was evaluated using identical 12-m diameter 6-port pipe arrays located inside and outside the structure. Tests were also carried out with a single-port system located at the center of the enclosure. The results presented in Figure 8 show that Version 5 of the system reduces wind noise in the monitoring passband to acceptable levels for monitoring purposes in ambient winds of up to 4.3 m/s, even when the pipe array inside the structure is replaced by a single inlet port. It is also interesting to note that noise levels recorded on the single-port system inside the structure at high frequencies are less than the electronic noise floor of the MB2000 microbarometer ($4x10^{-7}$ Pa^2/Hz), which is used at IS07 (and many other monitoring stations), in winds of up to 4.3 m/s. The performance of the single-port system is usually better than the performance of the 6-port pipe array at frequencies above 1.0 Hz, but the 6-port pipe array is more effective at lower frequencies. We have examined infrasonic signals recorded both inside and outside the enclosure at all frequencies of interest to see if these signals are affected by the enclosure. In all cases, we have found that infrasonic signals are not attenuated or distorted. The enclosure is virtually transparent to infrasound. In summary, the use of Version 5 of the wind-noise-reducing system at all array elements at IS07 Warramunga would effectively resolve wind-noise problems in the monitoring passband at this unsheltered IMS infrasound station.

A further example of the high degree of wind-noise reduction that has been achieved in the monitoring passband is illustrated in Figure 9 by the background noise waveforms recorded using Version 5 of the noise-reducing system under typical daytime conditions at IS07. The waveforms shown in Figure 6 were recorded near noon on 4 May 2007. It is clear from the results presented in Figure 6 that wind-generated noise in the primary monitoring passband has been dramatically reduced by the turbulence-reducing enclosure.

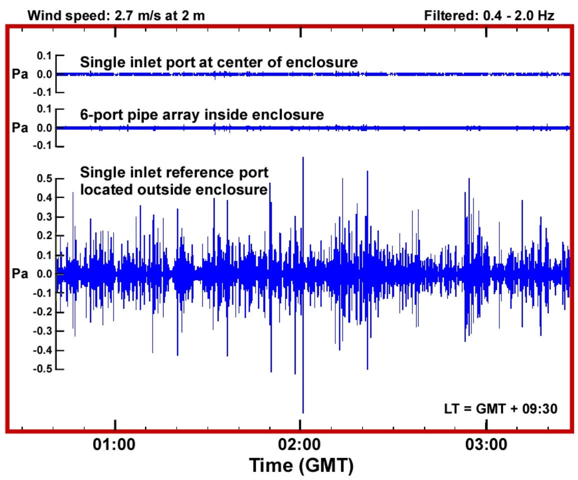

Figure 9. Comparison of background noise in the monitoring passband recorded on a single inlet port system and a 6-port pipe array system located inside Version 5 of the turbulence-reducing enclosure with background noise recorded simultaneously on a single inlet reference port located outside the enclosure. All traces have the same amplitude scale.

CONCLUSIONS AND RECOMMENDATIONS

The results of the detailed investigation of infrasound signal coherence properties presented here show that the monitoring performance of existing larger-aperture 4-element infrasound monitoring stations in the global network may be marginal for regional and distant explosions. The arrays at these stations should be upgraded to 8- or 9- element arrays.

The turbulence-reducing enclosure illustrated in Figure 7 provides a dramatic reduction in wind-generated noise in the infrasound monitoring passband. The use of this system can potentially resolve wind-noise problems at most infrasound monitoring stations. This system can be used to significantly enhance the performance of existing pipe arrays at established infrasound monitoring stations or, in some cases, as effective stand alone single-inlet port noise-reducing systems that do not require a pipe array. It is recommended that the use of this system should be considered in the design of all new infrasound monitoring stations

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