Recent developments in infrasound monitoring technology: application to CTBT verification

by Dr Douglas R. Christie

The signing of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) on 24 September 1996 and the establishment of the International Monitoring System (IMS) for Treaty verification has led to a rapid development in infrasound monitoring technology. The IMS 60-station infrasound network has been designed to detect and locate atmospheric nuclear explosions with a yield of one-kiloton[1] reliably. While the stations in this network have been located as uniformly as possible all over the globe, the distances between stations vary and the monitoring capability for explosions over the continental land mass areas is generally better than the monitoring capability over the vast open ocean areas in the Pacific and South Indian Oceans. At the present time, the infrasound network is limited to two-station detection for one-kiloton explosions that occur over most of the ocean regions. Global three-station detection capability is desirable since this would greatly enhance the reliability of the network, lower the global detection threshold and significantly reduce location errors. Recent developments in infrasound technology suggest that the monitoring performance and reliability of the IMS infrasound network can be improved substantially.

Infrasound stations in the IMS network are located in a wide variety of environments ranging from equatorial rainforests to remote wind-swept islands and the ice-covered wastes of the polar regions. As a result, wind conditions at these stations vary widely. Wherever possible, IMS infrasound stations have been located in dense forests in order to shield the station from wind-generated noise. However, shelter from the winds is not always available and it has been necessary in some cases to establish stations in areas with little, if any, protection from the ambient wind. The level of background noise due to wind-generated turbulence is often very low at night when the upper winds are decoupled from the surface by a nocturnal boundary layer. The onset of daytime convection usually leads to a rapid increase in wind noise as the upper level winds are reconnected to the surface layer. Wind-generated noise may prevent the detection of signals from distant explosions. Here, we describe a technique developed at the Australian National University (ANU) that can substantially reduce and often eliminate wind-generated noise at IMS infrasound stations.

Historically, almost all wind-noise-reducing systems have been based on a spatial averaging technique developed by Fred Daniels in 1959 in which the micropressure fluctuations at a series of inlets along a tapered pipe are summed at the microbarometer sensor. If the wind-generated noise is incoherent between inlet ports and if the signal is perfectly coherent, then this procedure results in an increase in the signal-to-noise ratio equal to the square root of the number of inlets. During the last decade, refined noise-reducing pipe array systems

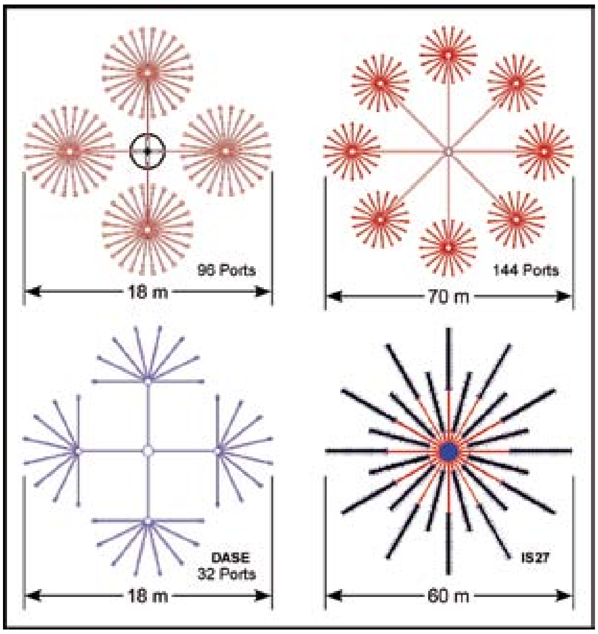

FIGURE 1: WIND-NOISE-REDUCING PIPE ARRAYS USED AT STATIONS IN THE IMS INFRASOUND NETWORK

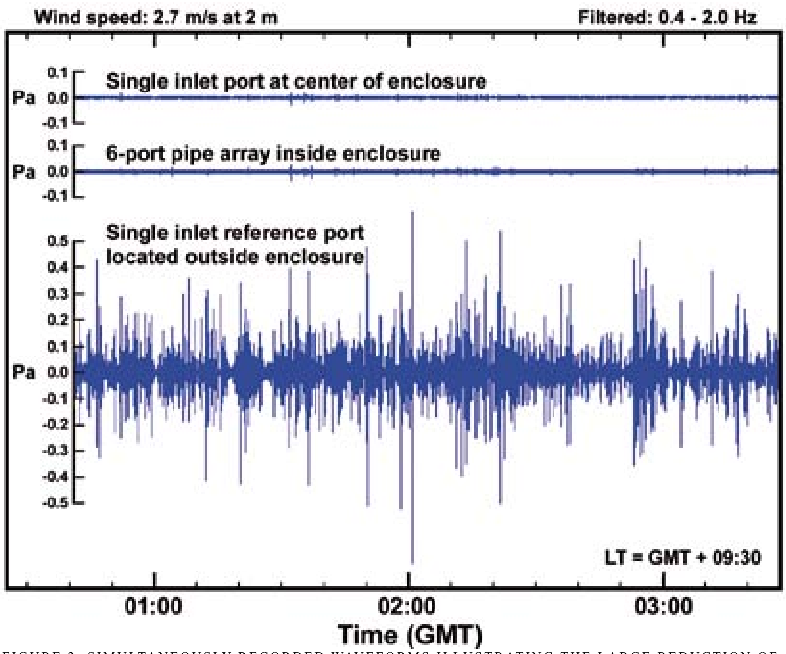

FIGURE 2: SIMULTANEOUSLY RECORDED WAVEFORMS ILLUSTRATING THE LARGE REDUCTION OF BACKGROUND NOISE IN THE PRIMARY MONITORING PASSBAND BY THE TURBULENCE-REDUCING ENCLOSURE DURING TYPICAL DAYTIME CONDITIONS

[1] The CTBT is a comprehensive treaty. No lower limit on yield is defined in the Treaty. For practical purposes, it was decided in the negotiations of the Treaty that the design of the global IMS infrasound network was to be based on the requirement that a one-kiloton nuclear explosion located anywhere on the globe should be detected reliably at a minimum of two monitoring stations. The global threshold for single-station detection is much less than one-kiloton. Two-station detection capability is required to determine the location of the explosion.

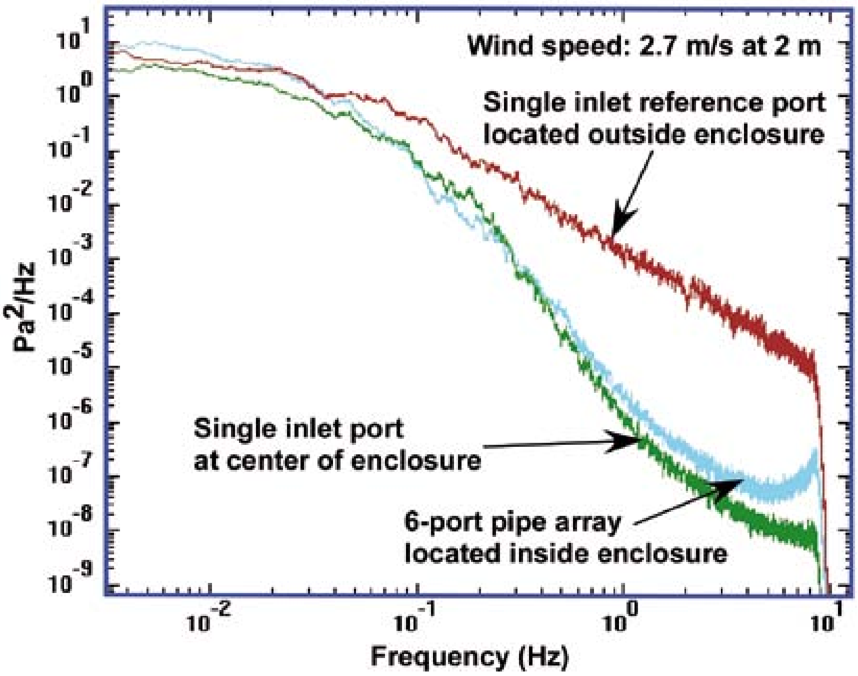

FIGURE 3: POWER SPECTRAL DENSITY OF BACKGROUND NOISE DATA RECORDED SIMULTANEOUSLY INSIDE AND OUTSIDE THE TURBULENCE-REDUCING ENCLOSURE DURING TYPICAL DAYTIME CONDITIONS

have been developed that are currently in use at IMS infrasound stations (see Fig. 1). These pipe arrays provide a very substantial reduction in wind noise, but the degree of noise reduction may not be sufficient when the station is located in an unsheltered area and winds are high. Wind noise reducing pipe array systems also have some disadvantages. The response of these systems is not always well known. In addition, they may be subject to unwanted resonances and may distort and attenuate higher frequency signals.

It seems clear that further refinements to existing pipe array designs will not lead to a significant improvement in wind noise reduction capability. The number of inlet ports and the size of existing pipe arrays has reached practical limits. A different approach to the problem of wind-generated noise is required. This new approach should result in a system that can reduce noise levels by at least a factor of ten over that obtained with existing systems. Research at the ANU during the past year has focussed on techniques which reduce wind noise levels by degrading turbulent eddies that generate noise in the primary monitoring passband (0.4 to 2.0 Hz).

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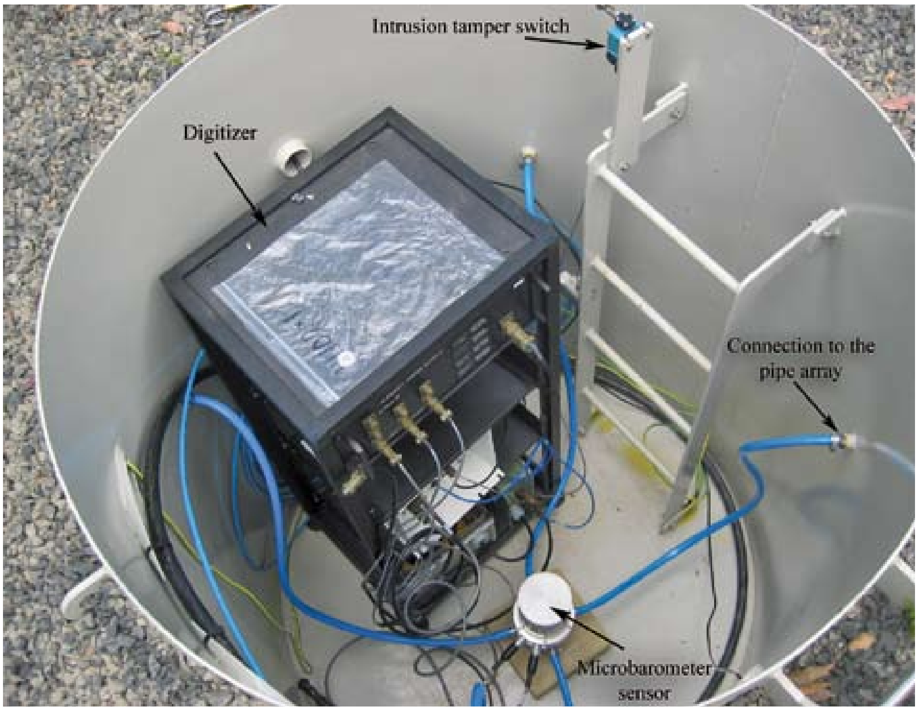

INSIDE OF AN INFRASOUND EQUIPMENT VAULT, INFRASOUND STATION IS04, SHANNON, AUSTRALIA

Glossary of terms

Nocturnal boundary layer
The nocturnal boundary layer is a thin layer of cooler air that forms at the surface over land during the night. This stable layer effectively prevents the ambient winds above this layer from reaching the surface.

Daytime convection
Daytime convection is a term used to describe the generation of thermal plumes induced by solar heating of the earth's surface during the day. The onset of thermal activity during the early daylight hours destroys the stable nocturnal boundary layer, thus reconnecting the ambient winds to the surface.

Pipe array system
Modern pipe array systems (see Figure 1) consist of a series of pipes that connect a large number of uniformly distributed inlet ports to a summing chamber at the inlet to the microbarometer infrasonic sensor. Samples of coherent infrasound and incoherent noise from all inlet ports are averaged at the sensor to give a large increase in signal-to-noise ratio.

Primary monitoring passband
This term is used to describe the range of frequencies (0.4 to 2.0 Hz) where infrasonic signals from distant explosions can be detected with optimum signal-to-noise ratio.

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This has proven to be quite effective and the results are very promising. The technique is based on the use of turbulence-reducing structures constructed from robust screens stretched over a rigid framework. A wide variety of such turbulence-reducing enclosures have been tested and this has led to a highly efficient design consisting of a number of chambers and baffles with excellent noise-reducing performance characteristics. An example of the results obtained using the latest version of the noise-reducing enclosure in typical daytime wind conditions is shown in Fig. 2 for waveform data in the primary monitoring passband. As can be seen from this diagram, wind-generated noise levels are very substantially reduced by the porous enclosure, even in the case where the pipe array is replaced by a single inlet port. It is worth noting that the porous enclosure has virtually no influence on the amplitude of infrasonic signals. The power spectral density plots shown in Fig. 3 provide a better illustration of the high degree of wind noise reduction provided by the turbulence-reducing enclosure at all frequencies. The results presented in this diagram show that the turbulence-reducing enclosure provides a very effective means for reducing wind noise in the primary monitoring passband for CTBT verification. In addition, the results show that a single inlet port system located at the centre of the enclosure is more effective than the distributed six-port pipe array that is also located inside the enclosure.

In summary, recent research at the ANU has shown that turbulence-reducing enclosures can be used to reduce or eliminate wind noise at IMS infrasound stations. These systems can therefore be used to enhance the performance of existing pipe arrays or, in some cases, as effective stand alone noise-reducing systems that do not require a pipe array. ■

Biographical note

Dr Douglas Christie was born in Canada and joined the Australian National University (ANU) in 1975, where he carried out research on nonlinear waves and infrasound. He assisted the Australian Government as an infrasound expert during the CTBT negotiations 1994-96. In 1997 he joined the IMS Division at the CTBTO and helped to establish the global infrasound network. He returned to the ANU in 2003. ■

A new platform for exchange with the scientific community

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Seismic

Eight external and five PTS contributions on seismic data processing dealt with various topics, such as enhancements of the automated processing at the PTS, decoupling experiments in Israel, improvements in local and regional earthquake monitoring, improvements in event discrimination and low magnitude event detection. The October 2006 DPRK event provided seismic data, which was utilized by several studies on the performance of the CTBT verification regime.

Radionuclide, noble gas and atmospheric transport

The DPRK event demonstrated also the crucial role of the radionuclide technology for the nuclear event classification. Moreover, the typical radioactivity release characteristics of underground events have shed a spotlight on the radio-xenon technology and the corresponding atmospheric backtracking methodologies (see also article on page 20). Seven external and six PTS papers elaborated on related topics, such as high-resolution monitoring and atmospheric backtracking studies, enhanced global modelling and data mining to improve global emission inventories, and machine learning algorithms utilizing pattern recognition techniques for radio-xenon event classification.

Conclusion

With this session, a platform of know-how exchange in the much debated field of nuclear explosion monitoring could be established. The 2008 EGU General Assembly will again take place in Vienna offering PTS the opportunity to sustain a scientific dialogue that is tailored to its need to stay abreast of the latest developments in the field and to provide its input to it.

Abstracts of all 42 contributions are available on a CD-ROM (Geophysical Research Abstracts, Volume 9, 2007) and on the 2007 EGU General Assembly web-page[1]. ■

Dr Frank Graeber is a geophysicist working aa a PTS Seismo-Acoustic Officer; Dr Andreas Becker is a meteorologist, working as a PTS Atmospheric Sciences Officer. Together with former PTS staff member Prof Dr Martin B. Kalinowski, University of Hamburg, they have initiated and co-convened the new European Geosciences Union exchange platform.

[1] http://www.cosis.net/members/meetings/sessions/accepted_contributions.php?p_id=251&s_id=4563