OPERATION OF A PROTOTYPE CTBT INFRASOUND ARRAY IN ARCTIC ALASKA

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ABSTRACT

A prototype Comprehensive Nuclear-Test-Ban-Treaty (CTBT) infrasound array was established in Fairbanks, Alaska in a wooded area on the campus of the University of Alaska in December 1999. The implementation of the array was carried out as part of the second phase of our studies of natural infrasound in arctic regions. A report on the earlier phase of our contract can be found in the Proceedings of the 21st Seismic Research Symposium[1] and on our web site: http://maxwell.gi.alaska.edu/~infra. In our implementation of the array four microphones were placed in the form of a triangle with one microphone placed near the center. During the winter months we also continued to monitor the response of three co-located microphones attached to different noise reducers to follow the relative effectiveness of the noise reducers in arctic conditions. These conditions ranged from severe winter cold with deep snow pack to the mild days of summer.

During the period of operation we detected several examples of naturally occurring infrasound as well as many man-made sounds. The naturally occurring infrasound signals of greatest interest are the 2-5 second period waves produced by marine storms that are termed microbaroms. We are studying these signals in order to estimate their spatial coherence. We believe that they can be identified and eliminated as a contaminating signal for CTBT arrays worldwide based upon their coherence properties. Other natural signals received included auroral infrasound, mountain-associated waves, thunder from summer storms and the eruption of the Japanese volcano, Mount Usu on March 31, 2000. A bolide that passed over central Alaska and exploded over Whitehorse, Canada on January 18, 2000 produced no detectable signal in our array. Man-made signals detected on our array are plentiful and varied. We witness every jet aircraft departure from the international airport located several miles away. Also recorded were the reports of military howitzers at the local army base as well as firework displays during holiday celebrations. Of special interest was the infrasound produced by two rockets launched from the University's Poker Flat Rocket Range located approximately 35 km from the array.

We present here an analysis of some of the signals mentioned above focusing on the properties that will help identify and eliminate these from CTBT analyses. We also include a summary of the effectiveness of the noise reducing arrays tested throughout the year.

Key Words: infrasound arrays, wind-noise reduction, microbaroms

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[1] Olson, John V. and Charles R. Wilson, Simultaneous Comparison of Three Co-located Pipe Systems for Wind-Noise reduction for use with Model #4 Chaparral Infrasonic Microphones at Fairbanks, Alaska, Proceedings of the 21st Seismic Research Symposium, Vol. 2, p. 169, 1999.

OBJECTIVE

Infrasonic arrays have been identified as one of the four basic sensors to be used as part of the Comprehensive Nuclear-Test-Ban-Treaty (CTBT) program. The geometry of an individual infrasound array has been specified and is to be comprised of four microphones, with three placed in an equilateral triangle and the fourth located at the center. Other more complex patterns of microphones have also been proposed to provide redundancy and additional noise reduction. Each microphone in the array has attached to it a "noise reduction array" composed of a series of vented pipes in various configurations. The pipes serve to average the local turbulent pressure field that is generated by local winds.

In the first phase of our contract work with the Department of Energy (DOE) we studied the effectiveness of three wind-noise reducing arrays. They were: 1) a 305 meter long Daniels tapered steel pipe vented with hypodermic needles every 1.5 meters; 2) a system of twelve radial porous "soaker" hoses, each with a length of 15 meters; 3) a hexagonal array of six 30-meter long sections of 2-inch diameter rigid pipe. The three arrays were attached to three microphones at the same site and data was collected continuously throughout 1999. The reports of this test were reported at the 21st Seismic Symposium. We have continued to monitor the effectiveness of each wind-noise reducer to the present time.

We are now in the second phase of our work in which we have deployed four microphones in the CTBT configuration in order to test the array itself in high-latitude, arctic conditions. A wealth of natural and man-made infrasound is present in the interior of Alaska and we are compiling a summary of the various types in order to be able to learn how to discriminate against them in the analysis of infrasound data used to detect man-made explosions. The principal contaminant of the spectrum of signals is the microbarom signal. Ubiquitous world-wide these signals have periods that are in the same range of that expected from man-made explosions.

RESEARCH ACCOMPLISHED

1. Phase 1: Investigation of the effectiveness of three noise reduction arrays

Our first research task was to gather information on the relative effectiveness of three noise reducers. We installed three noise-reduction arrays on three co-located microphones and began to log data continuously at a 100 sample/second rate. The unprocessed data has a Nyquist frequency of 50 hertz, well beyond the requirements of the CTBT. For analysis the field data are low-pass filtered and decimated 10:1 to give a 5 hertz upper band limit. The original unprocessed data and the decimated data are archived to cd-rom for convenience.

The first noise-reduction array is a 305 meter long Daniels tapered steel pipe that is vented with a hypodermic needle every 1.5 meters. The pipe axis lies roughly east-west. The second array is the Los Alamos National Laboratory/Comprehensive Nuclear-Test-Ban-Treaty (LANL/CTBT) prototype. This array is comprised of a series of radial porous "soaker" hoses, each 15 meters long giving a total aperture of 30 meters. The third system is a hexagonal array of six 30 meter long linear sections of 2 inch diameter rigid pipe. The six chords of the hexagon are vented every 1.5 meters with hypodermic needles and each chord is separately connected to the microphone by a ¾ inch diameter rigid pipe from the center of the chord. The total aperture of this array is 70 meters. While a detailed report on the effectiveness of the three arrays used was given previously[2] we will summarize the results here.

In Figure 1 we show a 24 hour segment from a very quiet day (July 24, 1999) in which the rms variation of the data is computed over 10 minute segments from each microphone. In this figure it can be seen that there is a diurnal variation in the rms signal level from each sensor. During the quietest interval near 1500 UT the rms levels for all noise reducers falls to levels near 0.01 Pascals. This is typical of the quiet conditions that prevail in the early morning hours (0800 UT is local midnight). The data shown in Figure 1, although representing one of the quietest days recorded, is typical in the diurnal variation in wind noise

[2] Ibid.

levels with the quietest levels occurring between local midnight and dawn. Also typical is the fact that the hexagonal array shows the smallest response to wind noise.

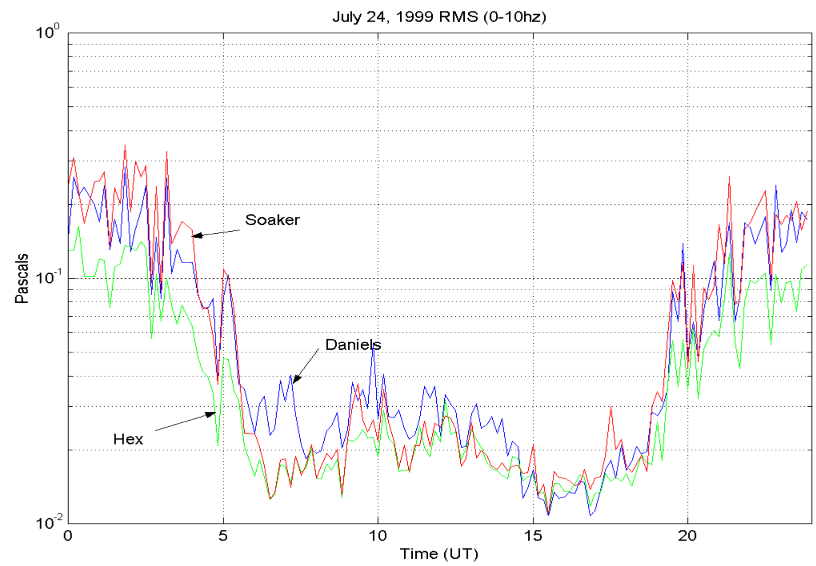

Figure 1. This figure shows the rms fluctuation levels from three co-located microphones for a quiet 24 hour interval on July 24, 1999. Typically quietest conditions occur near 1500 UT (0800 UT is local midnight). The relative wind-noise suppression of each of the noise reducers is shown. Note that the Hex array shows the lowest response to wind turbulence.

It is interesting to look at the power spectra computed from the data in Figure 1. In Figure 2 we show the power spectra of the three microphone outputs during the interval 1500-1510 UT. The data have been low-pass filtered and decimated to produce a sample interval of 1/10 second and a corresponding Nyquist frequency of 5 hertz. Notice that all three spectra are similar with relative minima near 1 hertz and a small peak between 2.5 and 3 hertz; the source of the peak is unknown but probably local and man-made. Also note that the hexagonal array is the quietest across the band of frequencies shown.

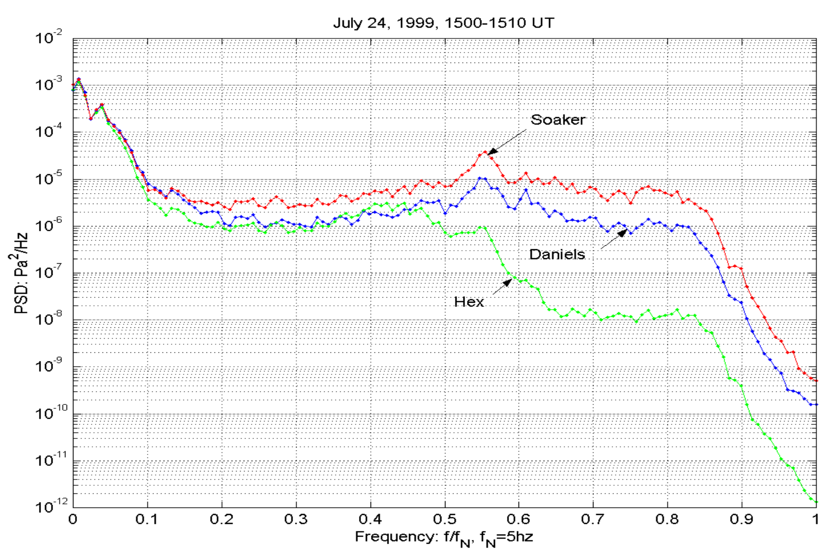

Figure 2. The power spectral density computed for the interval between 1500 and 1510 UT of July 24, 1999 (see Figure 1). During this quiet interval the hexagonal array shows the lowest response across the frequency band.

2. Phase 2: Analysis of data from a prototype CTBT array

In mid-December 1999 we began to assemble a prototype CTBT array. By the spring of 2000 four microphones were in place and operating. Data from the array continues to be logged at the 100 sample/second rage from each of the microphones with GPS time accuracy. The array is located in a wooded region located behind the Geophysical Institute on the University of Alaska campus. Figure 3 shows a map of the array and the exact locations are given in Table 1.

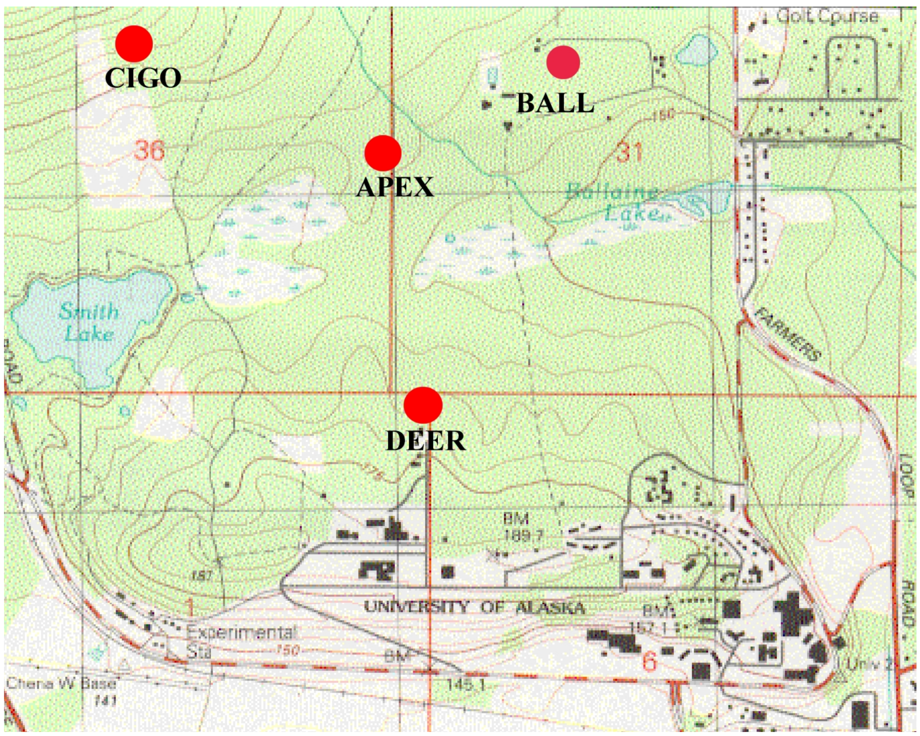

Figure 4. On the left, a map showing the locations of the four microphones that comprise the Geophysical Institute infrasound array. The microphones are located in a wooded area north of Institute on the campus of the University of Alaska. On the right, the impulse response of the array.

Table 1. Microphone Locations

Station	Latitude	Longitude	X (east) offset	Y(north) offset
Apex (APEX}	64° 52’ 19.3”	147° 50’ 41.3”	0.0	0.0
Ballaine Lake (BALL)	64° 52’ 27.2”	147° 50’ 03.3”	0.4978	0.2587
College Observatory (CIGO)	64° 52’ 30.6”	147° 51’ 30.7”	-0.6468	0.3486
Deer Yard (DEER)	64° 51’ 49.1”	147° 50’ 31.1”	0.1339	-0.9314

The impulse response of the array is shown in Figure 5. The principal images of the central lobes occur at wavenumbers with magnitudes greater than 8 which corresponds to frequencies greater than 0.5 hertz for acoustic waves propagating horizontally. This is important since if there were images of the central lobe at smaller values of the wavenumber then spatial aliasing would be possible for signals in the microbarom band between 0.1 and 0.5 hertz. Such aliasing would lead to biases and errors in the estimation of signal velocity and direction.

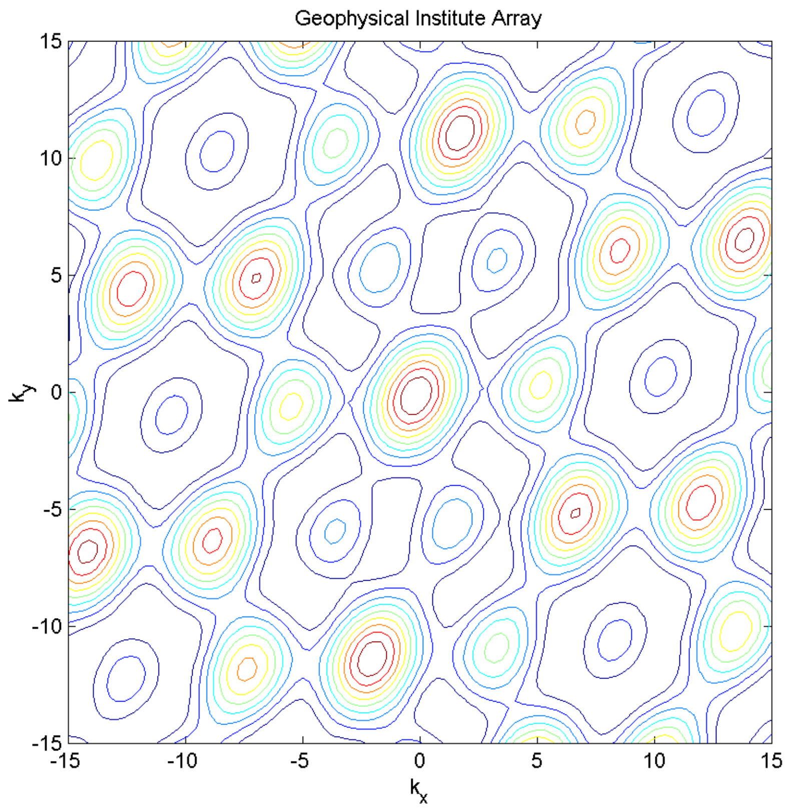

Figure 5. This figure shows the impulse response of the Geophysical Institute infrasound array shown in Figure 4. This impulse response is effectively the Fourier transform of the microphone array. The central lobe is surrounded by images determined by the symmetry properties of the array. Note the closest image lies at a distance of approximately k=10 corresponding to a frequency 0.53 hertz.

The impulse response of an array is important since it indicates the presence of spatial aliasing. The CTBT infrasound array is specified to have a fixed geometry and to operate over a frequency band from dc to 5 hertz. However, spatial aliasing can occur within this band. This can be seen by considering two microphones spaced at a certain distance. A sinsusoidal wave whose wavelength is equal to the microphone spacing will present the same phase to each microphone and so will not show any time delay as it moves across the two microphones giving, in effect, the appearance of an infinite velocity or of a wave incident from above. Now for a wave with wavelength slightly shorter than the microphone spacing the apparent phase speed is over estimated since the time delay measured between arrivals of points of constant phase is shortened due to aliasing. Thus, operation of an array at frequencies that have corresponding acoustic wavelengths shorter than the array can lead to inaccurate and biased estimates of the wave phase speed.

For a two dimensional array the information concerning spatial aliasing is contained in the impulse response. The various lobes in the impulse response are images of the central lobe in exactly the same sense that images of the spectrum of a signal are repeated for frequency aliased temporal data. Thus each lobe presents the wavenumber, or equivalently the frequency, of the wave whose wavelength will produce ambiguous simultaneous arrivals at the sensors in the array. For the target frequency band of the CTBT program that lies between 0.1 and 1 hertz, the corresponding wave numbers for acoustic waves range between 1.88 km^{-1} and 18.8 km^{-1}. Clearly there is the possibility of aliasing in the prototype CTBT array. In order to avoid aliasing we band-pass filter the data from each microphone prior to making estimates based upon array correlations.

As an example of the signals observed by the array we show in Figure 6 a set of microbaroms that were observed on July 15, 2000. The five minute segment of data displayed in Figure 5 shows the four microphone signals in the top four panels and a phase-aligned plot that is a result of the least-squares analysis of the data to determine the apparent horizontal speed and the direction of arrival. The analysis shows these signals to be acoustic: they have an apparent horizontal speed of 0.331 km/sec and an azimuth of arrival of 231 degrees.

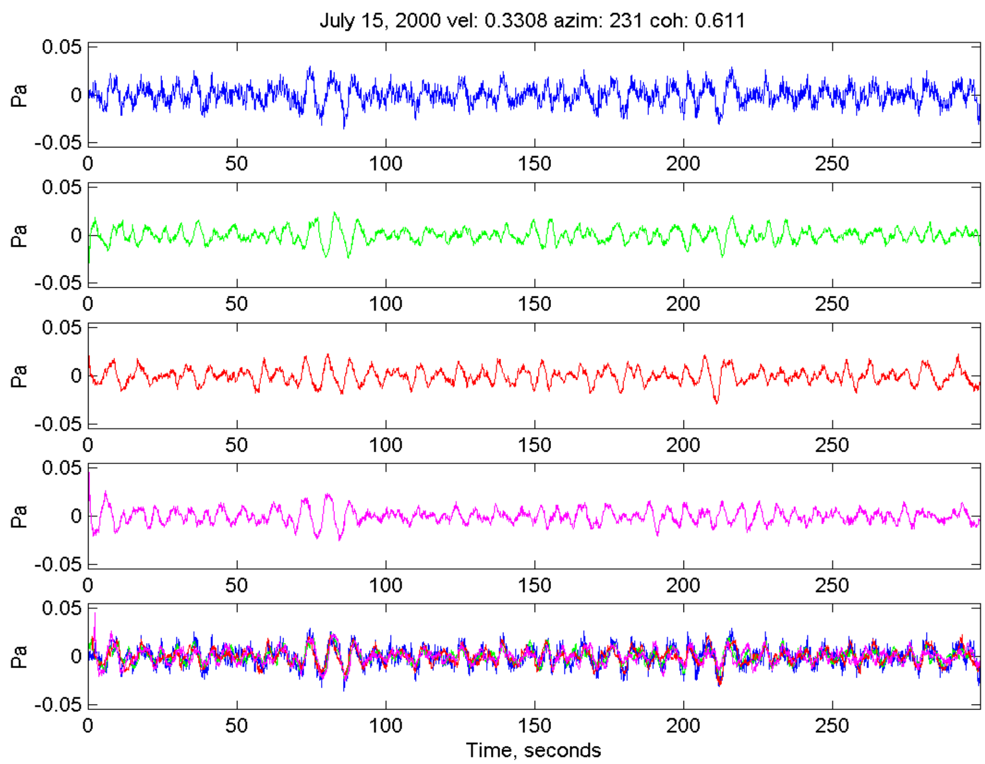

Figure 6. This plot shows microbarom data from July 15, 2000. The top four traces are the individual microphone output signals. The bottom trace shows a phase-aligned overlay as a result of the least-squares estimation of phase speed and direction of arrival.

The wavetrain displayed in Figure 5 is part of a nearly continuous train of signals from the same azimuth. In Figure 7 we show the least-squares estimation of the wave speed and azimuth of arrival for the entire day of July 15, 2000. There it can be seen that a coherent set of waves was present for several hours between 1100 UT and 1500 UT. The azimuth of arrival indicates that these waves were produced by a marine storm moving along the Pacific in near the Aleutian islands southwest of mainland Alaska. Although microbarom wavetrains are most prominent in the winter months they do occur throughout the year. A detailed description of the properties of microbaroms as well as other natural infrasound detected in polar regions is given on our web site http://maxwell.gi.alaska.edu/~infra.

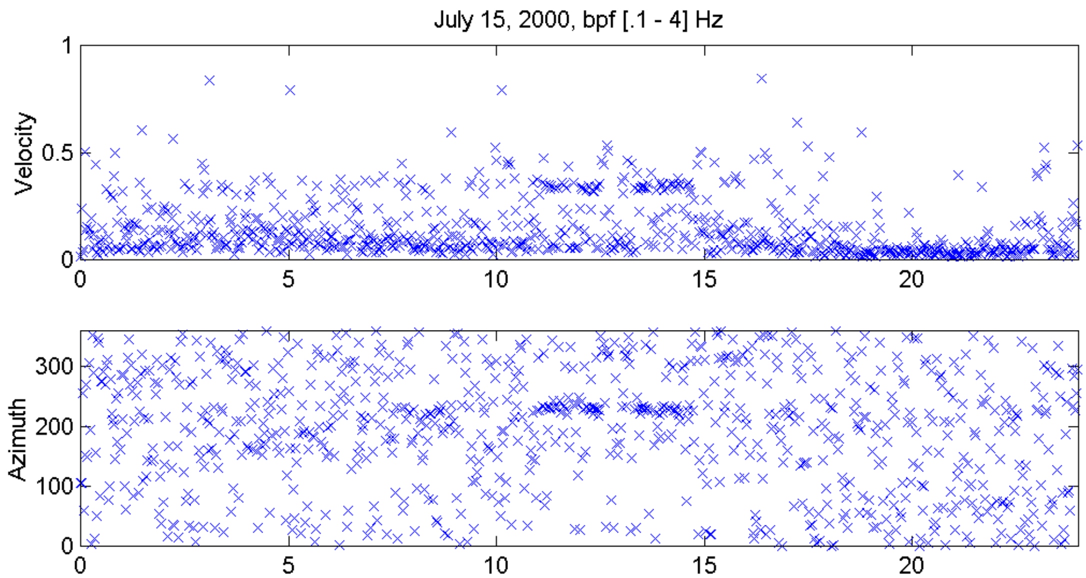

Figure 7. This figure shows the least-squares estimation of phase speed and azimuth of arrival for data from July 15, 2000. Each point in the diagram corresponds to an estimate made over a 100 second window located at that time. The interval between 1100 UT and 1500 UT represents the arrival of a microbarom wavetrain.

CONCLUSIONS AND RECOMMENDATIONS

We have operated a set of Chaparral microphones in Alaska for nearly two years as a test of the microphones, wind-noise reducing arrays and the prototype CTBT array configuration. Our research has been carried out in several stages and some questions are still being pursued. Nevertheless, our principal conclusions are as follows.

1. The hexagonal noise reducing array is the most effective at reducing the wind induced noise present at a microphone. Although pipes do have resonances it is possible to design the array so that the resonance occurs above the CTBT passband.
2. The prototype CTBT array using Chaparral microphones has operated successfully in central Alaska under the temperate weather of summer as well as the frigid climate of an Alaskan winter. We continued to log and analyze data through the year, even during periods when the ambient temperatures plunged below -40^{o} F.
3. The inclusion of a broad frequency band in the CTBT microphone and array specifications can lead to errors in estimation of signal parameters due to spatial aliasing. It is essential to band-pass filter data prior to subjecting them to array analyses that depend upon correlations between sensors.
4. We are studying the spatial coherence of microbarom signals. These signals, with periods near 5 seconds, are the principal contaminant of the frequency band in the range of the CTBT target signals. We have indications that the spatial coherence is not much greater than 1 km and so arrays larger than 1 km in aperture may be useful in discriminating against microbarom contamination.