ON THE ANALYSIS OF THE SPATIAL AND TEMPORAL STRUCTURE OF NATURAL INFRASOUND SIGNALS

John V. Olson, Charles R. Wilson and Curt A. L. Szuberla
Geophysical Institute, University of Alaska Fairbanks

Sponsored by the U.S. Department of Energy
Contract No. DE-FC04-98AL79802

ABSTRACT

The principal contaminant of the infrasound spectrum in the band between 0.2 – 0.5 hertz is the acoustic radiation associated with marine storms termed microbaroms.[1] These signals appear worldwide and, during winter months, can be the dominant signal during quiet periods. They tend to persist as collections of wavelets that last for hours and days. It is primarily against the spectral clutter presented by microbaroms that the detection of low-yield, man-made explosions must be made.

We have made the hypothesis that the spatial coherence of microbarom wavelets is limited to scales of approximately 1km. This is based upon previous experience operating arrays of various sizes at the Geophysical Institute, University of Alaska Fairbanks. In order to test this hypothesis we are conducting two experiments. In the first experiment we have begun to operate a single microphone at various distances from the permanent, four-microphone infrasound array located on the campus of the University of Alaska. By performing simple coherence tests as a function of the spacing of the microphone from the array we intend to make estimates of the mean coherence length. In the second experiment we are estimating the coherence length of microbarom wavelets in the time-series recorded by the microphones in the permanent array using Hilbert transform techniques. Preliminary estimates indicate that the microbarom has a spatial coherence of only a few wavelengths. Studies of historical data sets at Fairbanks indicate an average periods in the range of 3 – 7 seconds indicating a spatial coherence of the order of 5km.

The properties of the microbaroms and other coherent infrasound signals can be easily extracted from the broadband spectrum of incoherent signals through the use of the Pure-State filter. This is a coherence-based filter that, as distinct from other coherence-based analysis techniques, is not biased by the detector array geometry.

Key Words: infrasound microbarom coherence, signal discrimination

---

[1] A complete description of microbaroms and other natural infrasonic waves and a bibliography can be found on our web site: http://maxwell.gi.alaska.edu/~crw or http://maxwell.gi.alaska.edu/~infra

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2000**	2. REPORT TYPE	3. DATES COVERED **00-00-2000 to 00-00-2000**

4. TITLE AND SUBTITLE **On The Analysis Of The Spatial And Temporal Structure Of Natural Infrasound Signals**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Alaska Fairbanks,Geophysical Institute,Fairbanks,AK,99775**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Proceedings of the 22nd Annual DoD/DOE Seismic Research Symposium: Planning for Verification of and Compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) held in New Orleans, Louisiana on September 13-15, 2000, U.S. Government or Federal Rights.

14. ABSTRACT
See Report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

OBJECTIVE

The objective of this study is to describe the spatial coherence of microbarom signals with the expectation that such a description will enhance the ability to discriminate against these signals when detecting man-made explosions in the same frequency band. Microbaroms are small-amplitude fluctuations in atmospheric pressure that are apparently generated by marine storms. Lying in a frequency band between 0.1 and 0.5 hertz, they constitute the primary contaminant of the frequency band and they are ubiquitous. During winter months they are the dominant signal detected by infrasound arrays during quiet periods.

Previous experience has led us to hypothesize that the spatial coherence of packets of microbarom waveforms is limited to a few kilometers. The basis for this is the observations by the Geophysical Institute infrasound program that operated a large-aperture as well as a small aperture infrasound array for many years. Microbaroms are limited in frequency band and do not register as coherent signals across an array of large aperture.

We are pursuing this objective in two ways. The first is to perform actual measurements of microbarom coherence as a function of microphone spacing. We have one microphone that is not committed to array operation that can be moved to sites at varying distances from the normal array. Data from this microphone can then be used to study the variation of coherence as a function of distance. The second technique is based upon the analytic description of the waveforms as we detected them with the various array microphones. By characterizing the distribution of waveform coherence lengths we expect to translate this into an estimate of spatial coherence.

RESEARCH ACCOMPLISHED

In order to appreciate the complexity of the microbarom signal we show in Figure 1 a brief, five-minute, segment of data taken on July 15, 2000 during a period when microbarom signals were present in the array data. In most cases these signals are only apparent during quiet intervals. If there is significant wind driven pressure “noise” in the data it is necessary to band-pass filter the data near the microbarom passband. The top four panels in Figure 1 show the waveforms from each of the microphones. The bottom panel shows the data overlaid after signal time delays from station to station have been estimated using cross-correlation techniques. The time lags developed from cross-correlations of the microphone data are used to produce a least-squares estimate of velocity and azimuth of arrival. The estimators are the standard least-squares estimators as described in many textbooks. The details of our estimators are given in reports included on our web site http://maxwell.gi.alaska.edu/~infra.

As can be seen from Figure 1 the microbarom amplitudes are quite variable and there is the appearance of a sequence of superposed packets and noise that make up each microphone output. The fact that a single phase adjustment produces coherence across all packets for the entire five minute interval is an indication that the packets all move with acoustic speeds and are arriving from a common direction. In the case of these data the source appears to have been a marine storm off the Aleutian Islands southwest of the mainland of Alaska. The persistence of frequency, apparent velocity and azimuth of arrival for a sequence of microbaroms is not unusual. In fact wave trains can persist for hours or days. Figure 2 shows an analysis of the entire day of July 15, 2000. Each point on the plot represents the least-squares estimate of velocity and azimuth during a 100 second window. The data shown in Figure 1 have been taken from the sequence that lasts at least four hours between 1100 UT and 1500 UT. Finally, in Figure 3 we show the periodogram of the data from Figure 1. It is a simple Fourier transform that shows that most of the signal variance is contained between 0.1 and 0.3 hertz.

Since the microbarom wavetrain is persistent in its characteristics and narrow-band in frequency content we have turned to techniques based upon the Hilbert transform to extract some estimate of temporal coherence. From that estimate and the mid-band frequency under the assumption of acoustic propagation the spatial coherence, or packet size, can be inferred.

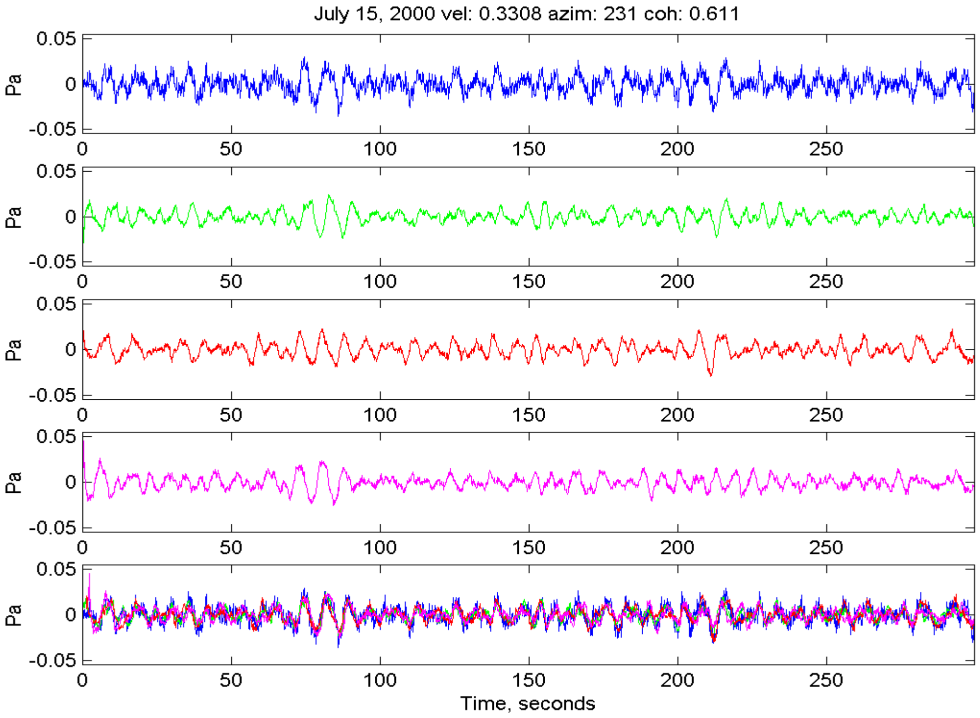

Figure 1. This plot shows a typical set of microbarom waves. Note the amplitude modulation. The top four panels show the data from individual microphones in the Geophysical Institute array. The bottom panel shows the phase-aligned data based upon a least-squares estimation of azimuth and velocity.

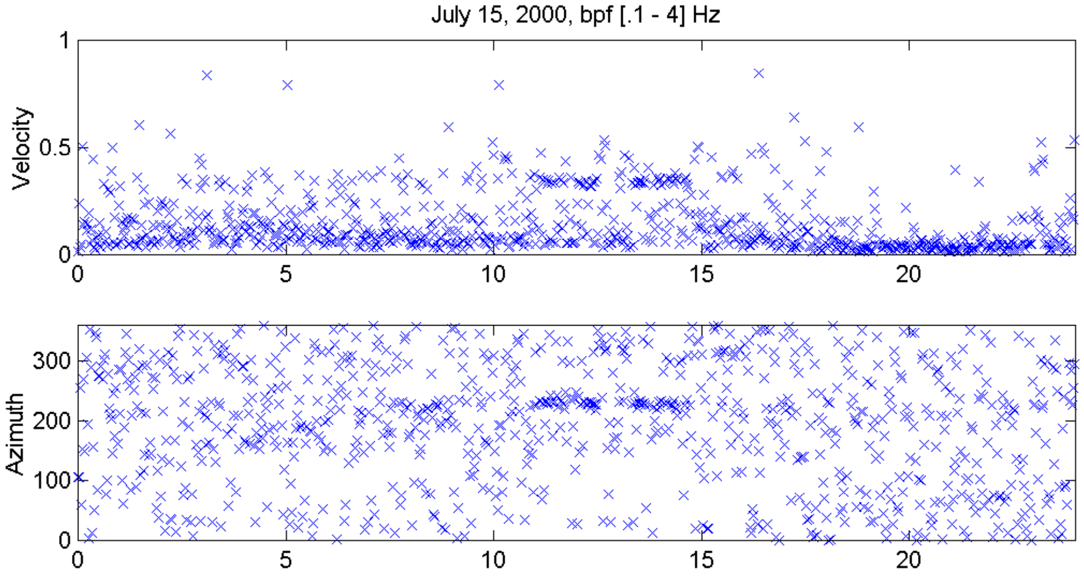

Figure 2. This plot shows the result of a least-squares estimation of azimuth and velocity for 24 hours of infrasound array data. Each data point represents the analysis of 100 seconds of data. Note the persistent azimuth and acoustic velocity trend between 1100 UT and 1500 UT. This is a microbarom wavetrain.

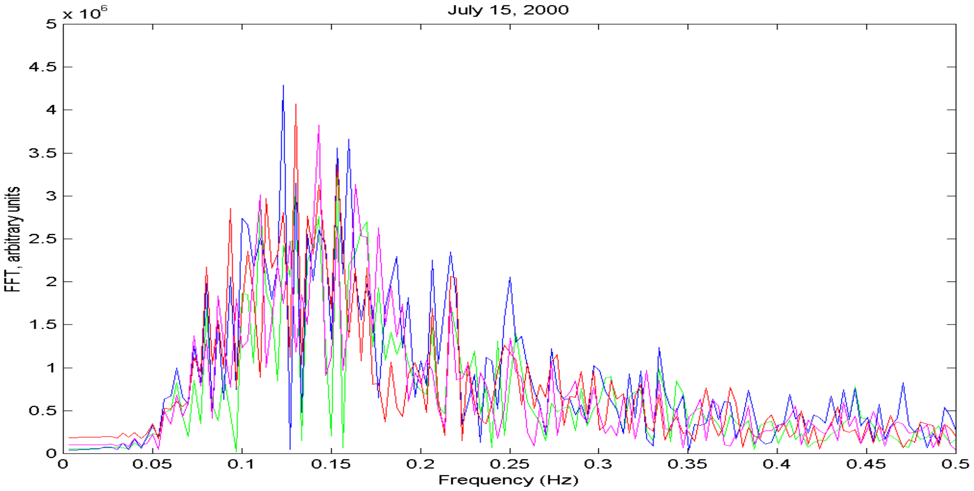

Figure 3. This figure is the periodogram showing the Fourier transform of the data in Figure 1. Notice that the waveform is relatively narrow band with most of the variance captured between 0.1 and 0.3 hertz.

With the expectation that the microbarom signals are narrowband with a persistent source azimuth we turn to the Hilbert transform to develop the analytic signal that represents the data from each microphone. Details of the Hilbert transform and the analytic signal are available in many textbooks such as, for example, the fine book by Bracewell, 1986. For a narrow-band function of one dimension the Hilbert transform produces a complex function called the “analytic signal”. The amplitude of the analytic signal is the envelope of the waveform showing what one might think of as the shape of the group of waves or the wave packet. The instantaneous phase of the transform is the frequency-time product so that the instantaneous frequency may be obtained from the time derivative of the phase. Sudden changes in instantaneous frequency are taken to be the sudden phase changes that are expected to occur at the boundary between two coherent wave packets.

We have begun the analysis of microbarom data in order to estimate the most likely packet length. Our estimation is based upon the following process. The steps in this process are illustrated in Figure 4. First we compute the Hilbert transform of the data and extract the envelope and phase. The top panel in Figure 4 shows the waveform from the Ballaine Lake (BALL) microphone on July 15, 2000 as taken from Figure 1. Also plotted in the top panel is the magnitude of the analytic signal to indicate the packet envelope. From the time derivative of the phase of the analytic signal we extract the instantaneous frequency of the signal. This is displayed in the second panel of Figure 4. The instantaneous frequency varies with time throughout the interval. In the bottom left panel we show the derived distribution of instantaneous frequencies. From this distribution we extract a mean (which characterizes the mean frequency of the entire wave train) and an estimate of the 95% limits. These values are transcribed onto the second panel (the dashed lines) as an indication of the expected variation of the instantaneous frequency. We then identify any values of the instantaneous frequency that are larger than the 95% confidence limits as phase breaks in the wave train. These locations are transcribed to the top panel as vertical dashed lines to show the phase breaks in the wave train. Finally, we are in a position to estimate the distribution of wave packet lengths in the time domain by measuring the distances between the vertical lines representing phase breaks.

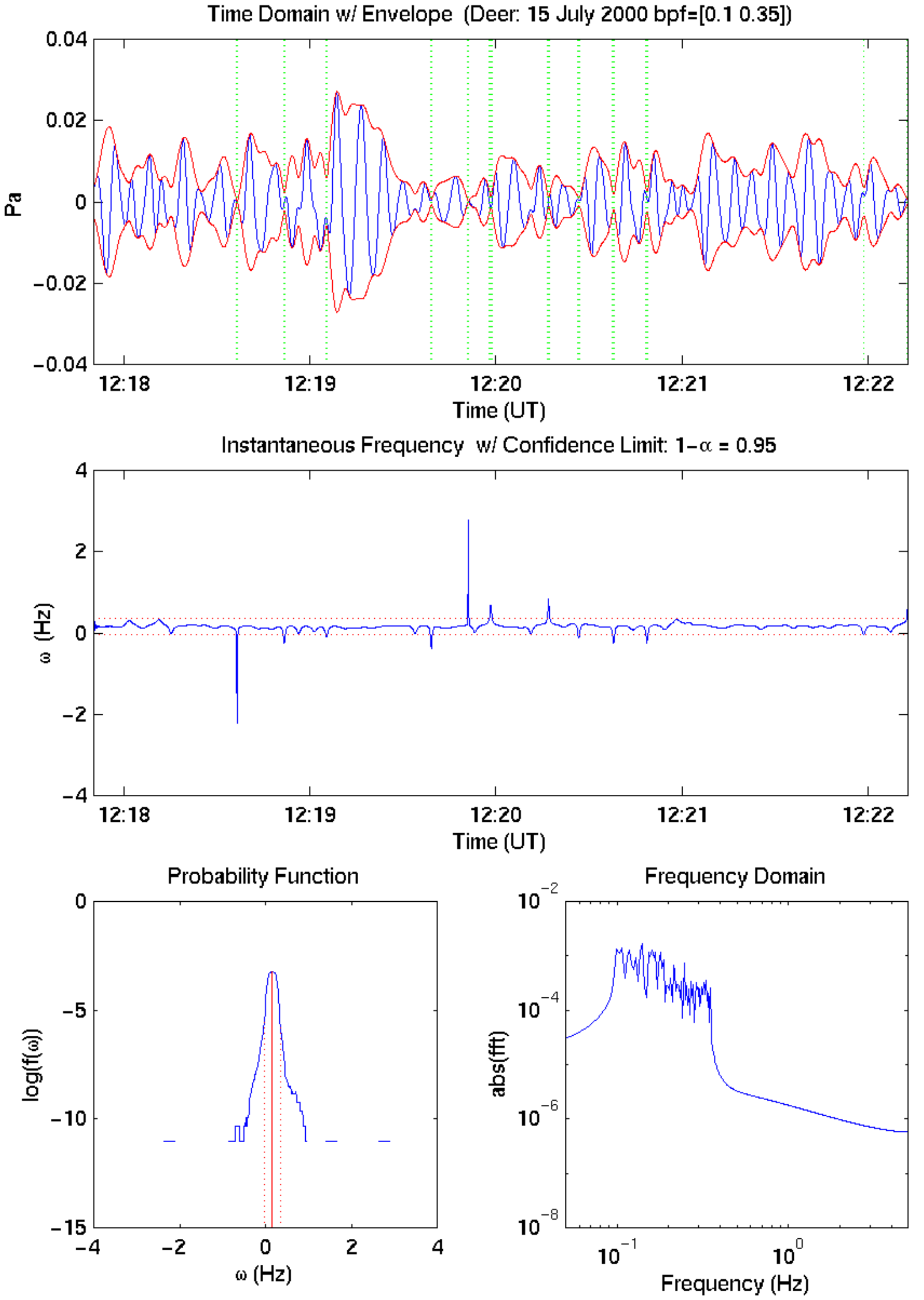

Figure 4. The top panel shows the waveform surrounded by the envelope derived from the analytic signal. The middle panel shows the variation in analytic signal phase along with 95% confidence limits derived from the distribution of amplitudes in the bottom left panel.

The distribution of distances between phase breaks calculated for the entire four hour interval between 1100 UT and 1500 UT on July 15, 2000 is shown in Figure 5. The four panels indicate the distribution in duration intervals obtained from each microphone. We have chosen to limit our search to intervals that are multiples of the mean period of the microbarom wave train. The distribution can be seen to be skewed towards low values in each case. The mean packet duration for each microphone is given in the plot panel for that distribution. We see that the means are all consistent and in the range between 22 and 25 seconds with variances that are fairly wide at approximately 20 seconds. With a mean wave period of about 6 seconds this indicates approximately four periods constitute the average packet length in time with a variance of the same order. At acoustic speeds these four periods span approximately 11 kilometers with a variance of the same order.

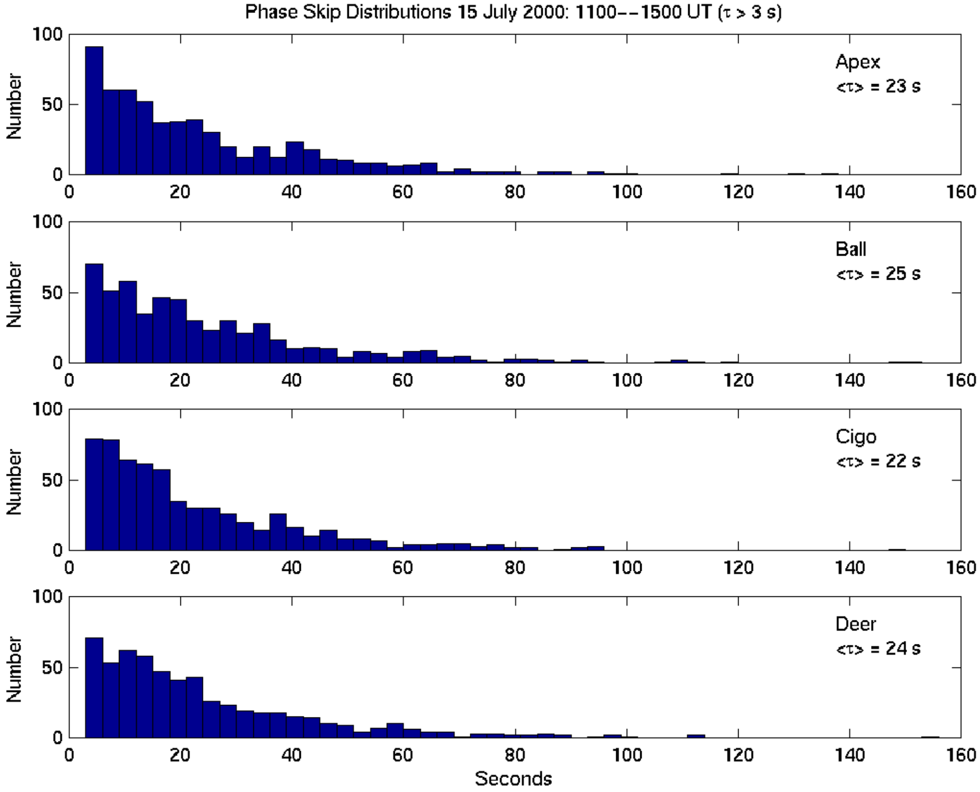

Figure 5. This plot shows the distribution of the intervals between phase jumps in the analytic signal for each microphone during the July 15, 2000 interval. Note the distributions have nearly the same mean and variances.

CONCLUSIONS AND RECOMMENDATIONS

Our analysis of the coherence time of the microbarom wave packets using analytic signal techniques based upon the Hilbert transform results in an estimate of the temporal coherence at about eight wave periods. Translated to distance by assuming acoustic speeds these eight wavelengths correspond to about 8 kilometers. The fact that the distribution of characteristic lengths is skewed and very broad compared to a basic wave period indicates that a simple one-microphone discriminate to be used to separate large-scale coherent signals in the band from microbaroms may not be as effective as hoped. The next step in the analysis will be the investigation of array apertures that allow discrimination to be made. In the meantime we plan to continue to investigate microbarom coherence extending our analysis to the cross-coherence between array elements.

REFERENCES

Bracewell, R., The Fourier Transform and Its Applications, McGraw-Hill, 2nd Edition, 1986.