

NPAL Acoustic Noise Field Coherence and Broadband Full Field Processing

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LONG TERM GOALS

The long term objective is to understand the characteristics of ambient noise to provide better models i) the distribution of their source mechanisms and ii) to provide better models to support advanced sonar array processing algorithms.

OBJECTIVES

The objectives are i) to characterize the ambient noise field coherence for the data recorded on the North Pacific Acoustic Laboratory (NPAL) and ii) to apply broadband, full field processing to characterize the sources in the local environment. Coherence measurements based upon field data are fundamental to understanding how the various sources of the ambient noise in the ocean superimpose and lead to both the observed spectral covariances and to the performance of advanced array processing algorithms such as matched field processing.. The data from the NPAL vertical line arrays (VLA's) are broadband and have an accurate array element positioning system, so we are examining the potential for broadband, full field processing.

APPROACH

One can construct a taxonomy for representations of spatial characteristics of ambient noise: **i) discrete, ii) diffuse and iii) sensor noise**; the temporal taxonomy is either narrowband or broadband. Discrete sources are target like and have a single degree of freedom representation, usually a plane wave, or more generally a Green's function.

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The important aspect is that in the limit of an ideal ocean, a discrete source is fully coherent across an entire array aperture, *i.e.* unity coherence. Diffuse noise is spread spatially coming from a continuous sector;. In the limit of all directions, it is isotropic with a coherence having well known sinc or Jo function distribution. Sensor noise is uncorrelated among sensors. Our approach with the NPAL data is to separate the noise into these three categories for both narrowband and broadband signal components. Examples of these include: i) machinery lines from either ships or submarines are modeled as a narrowband, discrete source; ii) earthquakes and marine mammals generate broadband, coherent sources; iii) wind noise on the surface generates broadband, diffuse coherence, often modeled using the Kuperman-Ingenito model, which is similar to sinc function distribution. In the limit of no ambient noise the sensors themselves generate broadband, flow noise uncorrelated among the sensors.

Our approach has been to separate the contributions to ambient noise into these three spatial components. The first step is to generate spectrograms for a few channels of the VLA. This identifies transient events such as earthquakes and marine mammals. Moreover, strong tonals from shipping can be identified. Often the ships are close enough to identify the interference pattern generated by the direct and surface reflected paths. Vertical beamforming for selected frequency bins is then done. This must be confined to frequencies less than 20 Hz because of spatial aliasing. (There is a significant amount of near vertical power at the NPAL site and this limits extending the frequency beyond the aliasing frequency.) Next, we examine both broadband and narrowband coherence among all elements and all five VLA's. Finally, matched field processing using several sources for replica computation (*in situ* measured SVP's and Levitus) and these are compared across the frequencies where we believe to be from the same ship, or source.

WORK COMPLETED

We have generated LOFAR grams (short-time Fourier analysis) for virtually all of the NPAL data. These spectra indicate a lot of variability in the data. This includes both near (one directly across the array) and far field shipping, marine mammal vocalizations, earthquakes plus many transient events. The ensemble of spectra emphasize the well known observation that ambient ocean noise is far from ubiquitous and has considerable variation, *e.g.* spectral levels vary by as much as 40 dB. We have also used plane wave beamforming for the frequency range 0-20 Hz where the array is not spatially aliased. There are many examples of ducted propagation at low frequencies and the trend to high angle propagation at the higher frequencies. Probability densities for some selected events which suggest a non-gaussian distribution, especially with high shipping. These have all been reported at NPAL or ASA meetings.

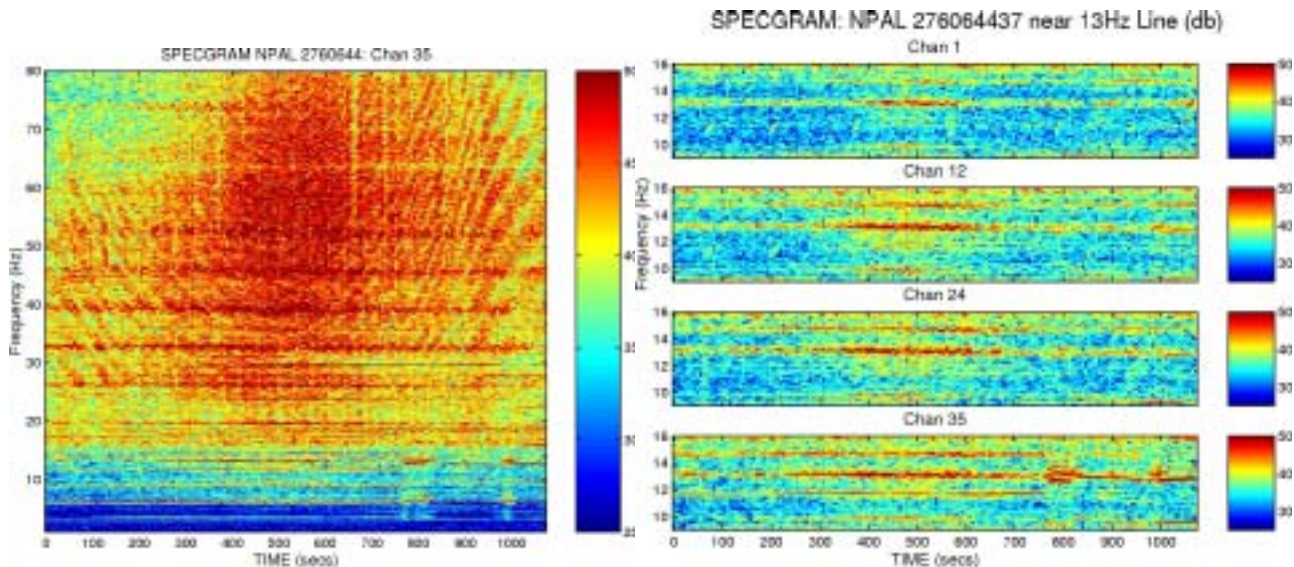
Recently, we have addressed spatial coherence and started some matched field processing on the NPAL data. One needs to approach the coherence from both narrowband and broadband perspectives. In the narrowband we first try to identify a strong tonal in the shipping or a frequency bin in a high amplitude event such as whale vocalization. We then crosscorrelate time segments across the array to measure both the vertical and horizontal coherence. The whales and earthquake events are highly coherent ($> .6$); however, the shipping is closer to spatially spread noise. This may be due to a low SNR in the analysis bin. For broadband coherence we simply cross correlate a band of data across. These lead to crossing patterns which correspond to local multipath peaks.

Implementation of the matched field algorithms has been more difficult since we do not have SVP's at the time of the processing. In addition, some of the sources are distant so range variability is an issue.

Nevertheless, we have some preliminary results illustrated in the next section indicating the tracking of a ship as it passes through CPA near the array.

RESULTS

Some representative results are indicated in the figures below. Fig.1 indicates broadband and narrowband LOFAR grams when a ship passed near the array.



***Figure 1: Broadband and narrowband LOFAR grams of a ship passing near one of the NPAL VLA's. The broadband LOFAR is for channel 20 in the middle of the 40 element VLA while the narrowband are at channels 1 (shallowest), 12, 24 and 35. The striation patterns are evident on the broadband while low frequency tonals 13. Hz and 14.8 Hz.
(The tonal at 14.8 Hz is subsequently used for the matched field processing.)***

Two examples of coherence analysis across the full NPAL array are illustrated in Fig. 2. The left panel is from a broadband source and specifies the peak coherence across all lags reference the center element of the NPAL arrays. The windowing was for 25 secs, or approximately the duration of the whale vocalization. The signal is very coherent and supports the concept that canceling loud discrettes can make a difference in the performance of a vertical array. The right panel is for distant shipping; however, now the parameters are the lag and position in the array. There are a number of lines crossing the display. These correspond to the dominant multipath from a distant ship. They are coherent within the reference array (VLA3) and remain so across the arrays. These data can be converted into a horizontal coherence on each path if the SNR was high enough.

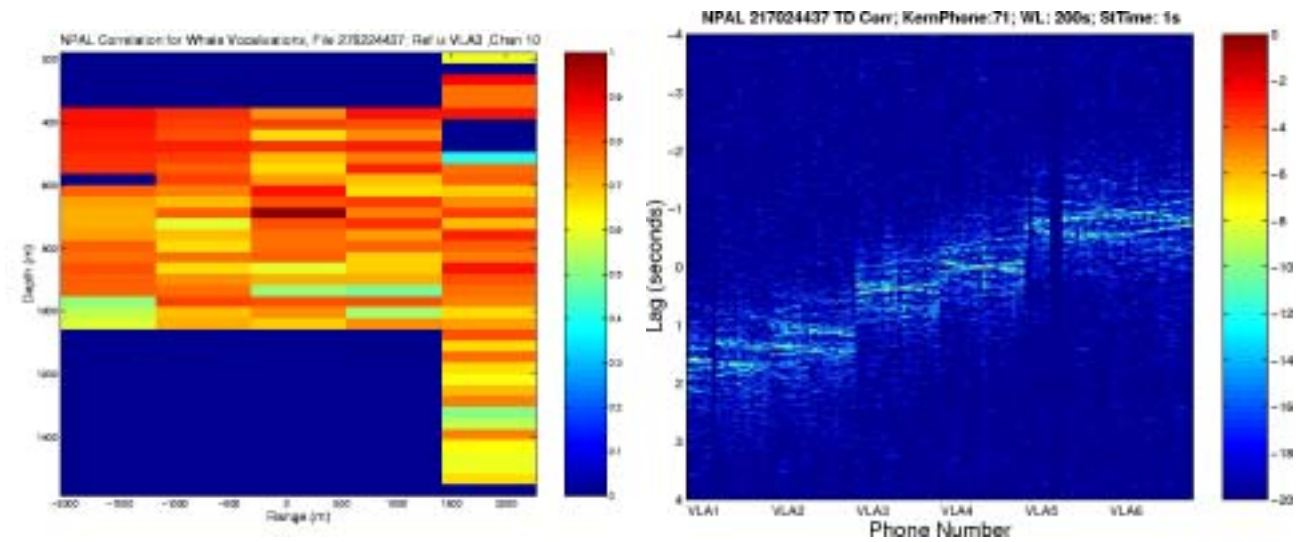


Figure 2: Spatial coherence across the full NPAL array. The left panel is a broadband (15 +/- 2.5 Hz whale chirp vocalization. The reference is the middle element of the VLA3 with the right being VLA1 and the left VLA5 (40 elemnts) The cohernces are generally in excess of .5. The right panel is for a shipping tonal plotted as a function of phone number within the VLA's and lag delay. The reference is again the center array element. The coherences are lower, ~.3; however, one can identify the multipath coherence at the lags across the 5 arrays.

We have successfully demonstrated matched field processing using one of the 40 element NPAL array. We used a tonal centered near 13 Hz for the signal. In Fig. 3 wav a sequence of MFP outputs every 18 secs running from 1 –163 secs on the left and from 181 to 343 secs on the right. Each panel scans the range from 0 – 30 km and depths from 0 – 1000 m. At the start one observes the maximum response near 0 depth and 5 km. In addition there are sidelobes at larger ranges. One can observe that as time increase the location of the source closes on the array and is nearly overhead at the end. Further tracking was not possible at this frequency has not been done because the ship changed its machinery line up, so all the frequencies shifted.

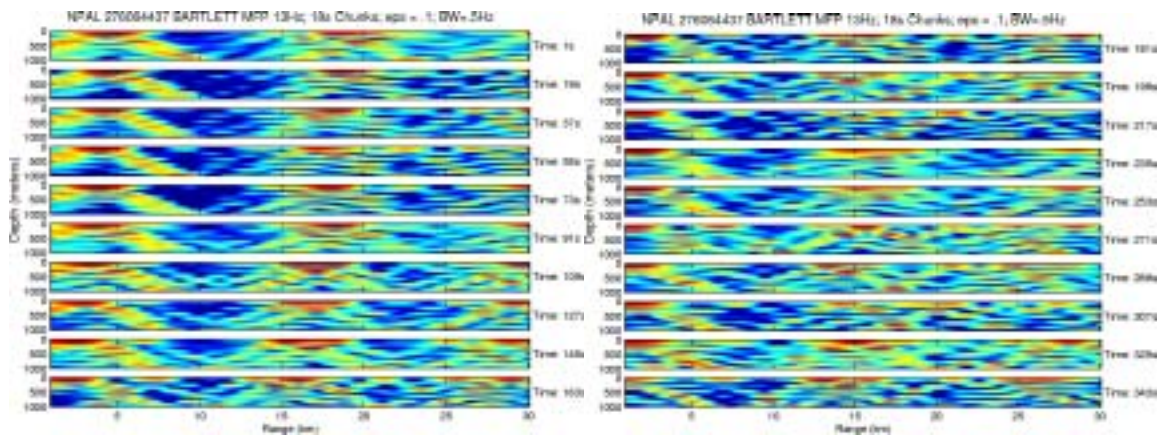


Figure 3: Matched field processing outputs from the 40 element NPAL array indicating a ship passing across the array. Each panel is a range-depth ambiguity plot for 18 secs.

We have yet to use the full NPAL array which is quite tricky because it involves nearfield focusing where small perturbations in the horizontal position of all the VLA elements have a significant impact. We have attempted to proceed to broadband processing, but there are not enough tonals in the unaliased frequency band of the array; moreover, there are several ships present, so selecting the correct ones to combine is ambiguous.

IMPACT/APPLICATIONS

The long term impact of this for the Navy involves the performance of VLA's. Spectral structure and time domain coherence have long been specified. In addition, the coherence with towed arrays has also been extensively studied. Here we are making a detailed analysis of all the ambient signal components propagating across the NPAL arrays with the goal of understanding how each can be processed to improve sonar performance. Since there are a number of VLA systems being considered by the Navy, these results will be useful in analyzing each of these systems.

TRANSITIONS

None

RELATED PROJECTS

This analysis of the ambient noise is related to the Acoustic Observatory Testbed Array now planned for deployment by ONR. In addition, several of the analysis methods have been used for the grant "Stochastic Matched Field Processing and Array Processing in Snapshot Limited Environments," sponsored by ONR Code 321US..

PUBLICATIONS

Baggeroer, A.B. and Scheer, E.K., w/ the NPAL Group: J. Colosi, B.D. Cornuelle, B.D. Dushaw, M.A. Dziechiuch, B.M. Howe, J.A. Mercer, R.C. Spindel and P.F. Worcester, "Noise Field Statistics and Coherence for the NPAL Array," *J. of the Acoustical Soc. Of America*, vol 108, (May, 2001)