

High Frequency Acoustic Channel Characterization for Propagation and Ambient Noise

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LONG TERM GOALS

Predicting underwater detection capabilities as well as vulnerabilities depends strongly on the characteristics of the ocean acoustic propagation channel. Operational advantages can be obtained by exploiting the ambient noise field to characterize the channel. The long term goal of this research is to determine methods that take advantage of the ambient noise field to extract useful information about the ocean operating environment.

OBJECTIVES

Passive techniques that exploit the ocean ambient noise field are useful when active sonar is not practical or feasible. Situations include covert operations, low power UUV operations, or when operating in areas where sonar is prohibited due to environmental restrictions. The objective of this year's work is to use ambient noise to determine bathymetry (a fathometer) and to image the seabed and sub-bottom layer structure.

APPROACH

The approach is to use the cross-correlation properties of the ambient noise field. Correlating the noise field measured by two sensors one can recover a function that closely resembles the two-point Green's function representing the impulse response between the two sensors. In the approach used here, the noise correlations are used to produce a passive fathometer that can also identify seabed, sub-bottom layers. In principle, just two hydrophones are needed— given enough averaging time. However, we have developed a method to combine the cross-correlations of all hydrophone pairs in a vertical array to obtain a stronger signature and greatly reduce averaging time. With a moving (e.g. drifting) vertical array, the resulting algorithm yields both a map of the bottom depth (passive fathometer) and the locations of significant reflectors in the ocean sub-bottom.

Sound generated from wind action on the surface can be modeled as an infinite sheet of point sources located just below the surface. As a simple example, consider the fluid halfspace environment shown in the left panel of Fig. 1. The cross-correlation between the modeled noise at a reference hydrophone located at range 0, depth 20 m and all possible receivers in the vicinity (at 500 Hz) is shown in the right panel of Fig. 1. The cross-correlation field looks like the source of sound originates from the reference hydrophone and *not* at the surface. Note, however, that unlike a true source there is directional shading.

Report Documentation Page

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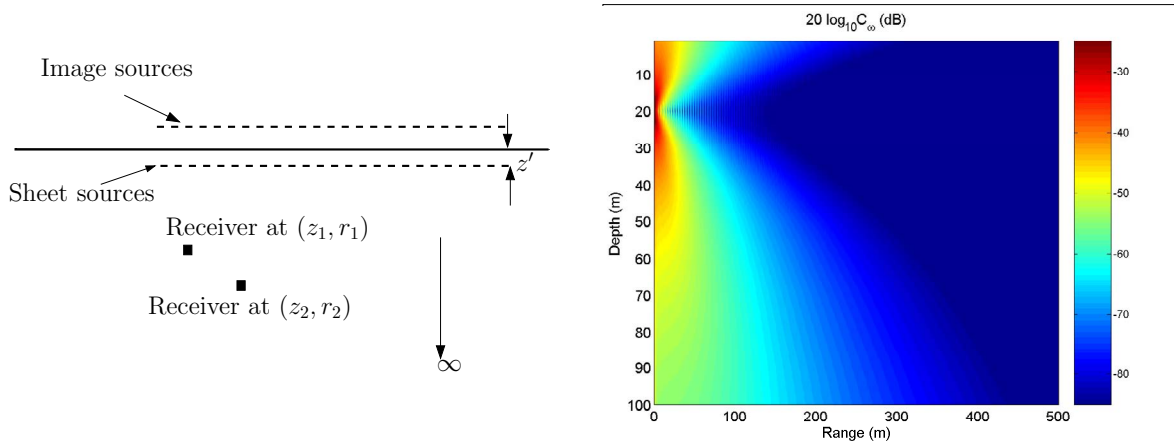


Figure 1: Left panel shows the geometry for the noise in a fluid halfspace problem. The pressure release surface gives rise to image sources. On the right, the cross-correlations (magnitude-squared on a decibel scale) between a reference hydrophone and those around it is shown. The source appears to be at the location of the reference hydrophone at range 0, depth 20 m and has a dipole-like radiation pattern.

By extending this idea to time-domain signals (broadband) the apparent “source” from cross-correlating noise signals can be used in ways similar to a fathometer or bottom profiling sonar (e.g. chirp sonar). Consider next a simulation with an array of 32 vertically separated hydrophones located between depths of 70.18 m to 75.76 m (0.18 m spacing) in the 100 m deep water column. The water column is iso-speed at 1500 m/s. The sediment is made up of a top 3-m layer with sound speed of 1550 m/s, density of 1.5 g/cm³, and attenuation of 0.06 dB/λ. Below is a 5-m layer with sound speed of 1600 m/s, density of 1.65 g/cm³, and attenuation of 0.2 dB/λ. The half-space below has sound speed of 1700 m/s, density of 1.65 g/cm³, and attenuation of 0.2 dB/λ.

The first processing step is to correlate a reference hydrophone in the array with each of the others to form 32 (in this case) cross-correlation time series. Delay and sum beamforming (steering towards endfire) is applied to the 32 time series to combine them into one. This time series looks like one that would be generated by a source at the location of the reference hydrophone and received on the array. This is repeated using each of the hydrophones in the array as the reference. The result for this first processing step is shown in panel (a) of Fig. 2. The 32 time series in panel (a) can be aligned by delay and sum beamforming a second time (also in the endfire direction). The result is a single, time-series shown in (b) of Fig.2. The initial peaks in the time series are due to the “direct” paths on the array and the delay times are related to the length of the array. More importantly, the bottom bounce arrival is clearly evident at 0.04 s and is followed by the returns from the seabed layers.

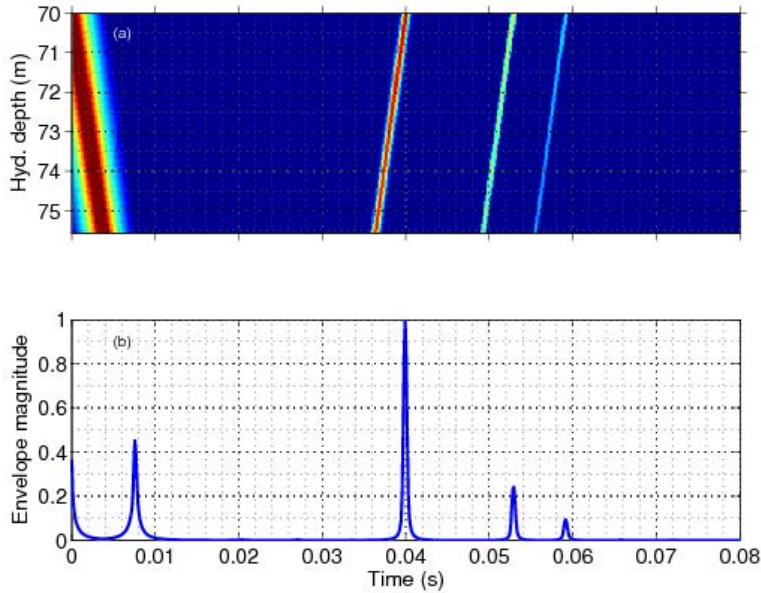


Figure 2: Simulation- Panel (a): Stacked, delay and sum beamforming using each of the 32 hydrophones as a reference. Note, there is a bottom reflection corresponding to the water-seabed interface and two sub-bottom reflections corresponding to the two layers. Time series magnitudes are shown on a decibel scale with a range of 18 dB. Panel (b): the second stage of beamforming (i.e. beamforming the sequences shown in Panel (a)). This is on a normalized linear scale where the envelope has been taken.

WORK COMPLETED

A technique has developed that uses ambient noise to determine bathymetry and seabed layering. A theoretical description was developed and supported with numerical simulations and measurements. These are partially described here and are more completely documented in publications [1-3].

RESULTS

The first result of the fathometer/seabed-imaging processing uses measured data of opportunity from the 2001 NATO Undersea Research Centre, ASCOT-01 experiment that took place near the Stellwagen Bank off the Northeast coast of the U.S. The site was in 101 m water depth and a sound projector was used so the ambient noise had to be carefully windowed from the time-series. This experiment had a fixed array with measured hydrophone and water depths so it verifies the processing in a known environment. We averaged a series of 0.5 s snapshots (over several hours) to produce, effectively, about a 30 s average. We used 33 elements in a 0.5-m spaced array with top hydrophone measured to be 52.25 m from the seabed. The frequency band considered is 200–1500 Hz. In Fig. 3, panel (a) shows the output after the first stage of beamforming. The bottom bounce is weak yet visible. In panel (b) of Fig. 3, the second stage of beamforming is applied and the bottom bounce is clearly visible. The peak near 0.07 s, in panel (b) puts the estimate of the distance to the bottom at 52.5 m, well within the experimental error on the measured hydrophone distance of 52.25 m. In this case, the array reference was the shallowest channel at 52.25 m which is near the mid-water depth, and if a surface bounce were present, it would nearly interfere. To break the symmetry, the array beamforming was shifted to the deepest hydrophone and this is shown in panel (c) of Fig. 3. As predicted, in neither

case, is there evidence of a surface bounce. This may primarily be due to the beamforming de-emphasize this return, but is also predicted to be weaker than might be expected from a true source. Sub-bottom returns are also present, but these could not be verified for correctness.

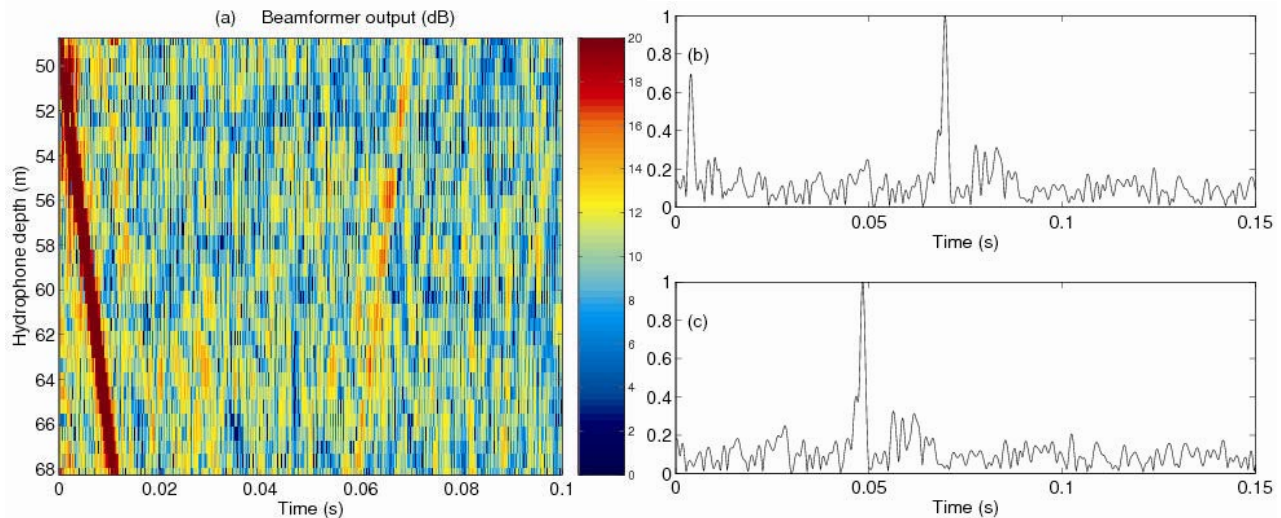


Figure 3: Panel (a) on the left shows the ASCOT-01 ambient noise processing after the first stage of beamforming. Near time 0.06-0.07 s the bottom bounce is faintly visible. In (b) (top right panel), is the second stage of beamforming showing the bottom bounce at around 0.07 m. In (c) (lower right panel), is the same processing with the array center shifted to the deepest hydrophone.

The second experimental example is taken from a controlled set of data that were collected on a drifting array during the NATO Undersea Research Centre's Boundary 2003 experiment. The drifting array has 32 hydrophones spaced at 0.18 m and can record noise up to 4 kHz. The wind varied during the experiment but was, on average, approximately 15 knots. At the time of the experiment, the depth of the array was not a critical factor and was therefore not measured carefully. However, it was reported that the hydrophones were to be kept less than about 80 m but were probably between 70–80 m. Approximately 70 s were averaged to form the cross-spectral density and produce a single fathometer time trace. Following the array drift, seismic reflection data were collected to image the sub-bottom layers. The seismic reflection data was collected by towing a Uniboom source (approximately 0.5–10 kHz) with a 10 element towed array behind the NATO R/V Alliance. This sonar is designed to measure both the bathymetry and the strongest reflectors from the seabed. It was only possible to approximate the drifting array tracks with the Uniboom tracks. In Fig. 4, the ambient noise (panel (a)) and Uniboom (panel (b)) processed data are shown. For these displays, the data envelope of the time-series are taken and put on a decibel scale. There is a 12 dB dynamic range in the color scale. Since the array depth and position were not known exactly, some alignment of the ambient noise and Uniboom data were made with the data itself. The depth of the array was taken as 73.5 m for the entire track. The range of the array along the track was allowed to slide a few hundred meters. However, a single range correction was used for the entire track. There are features in both (a) and (b) that are similar as far down as 25 m into the seabed.

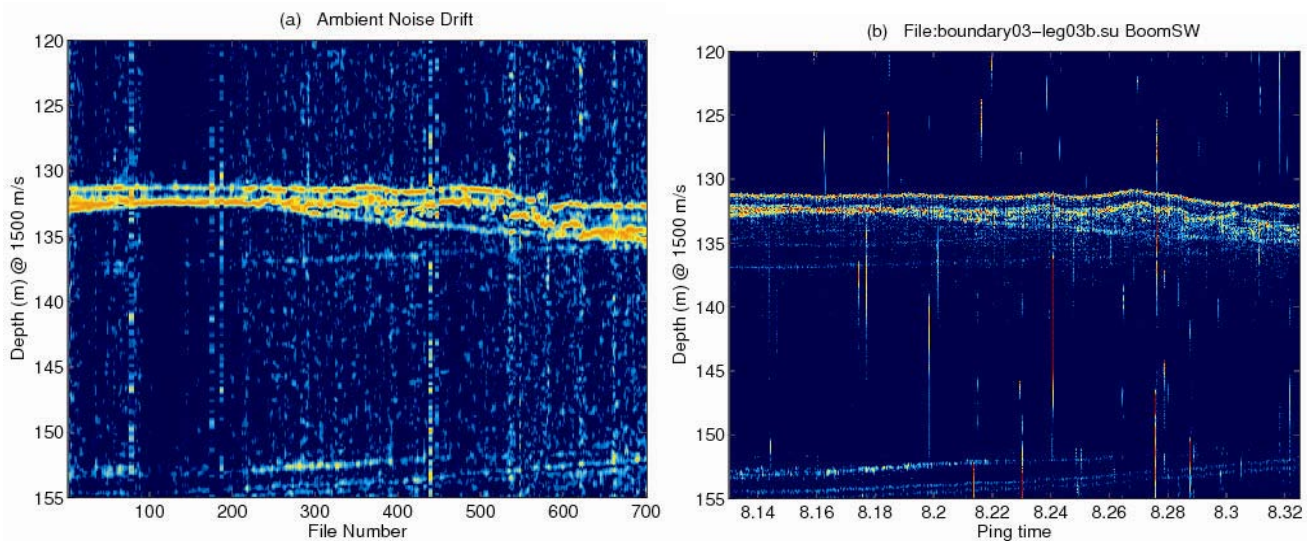


Figure 4: In panel (a) (on the left), the ambient noise fathometer processing is used and in panel (b) (on the right), approximately the same track using a towed Uniboom sub-bottom profiler. The y-axis is two-way travel times converted to depths using 1500 m/s sound speed.

IMPACT/APPLICATIONS

This work has the potential for significant impact on several sonar systems and underwater acoustics applications (e.g., ASW, MCM, underwater acoustic communications). Knowing the seabed properties will improve at-sea situational awareness by being able to accurately predict acoustic propagation. Because this is a passive method it can be designed into a system used for covert activities, low power applications and can be used even in environmentally restricted areas.

RELATED PROJECTS

This research has done in collaboration with Michael Porter and the ONR High Frequency Initiative. We have also been working with Chris Harrison at the NATO Undersea Research Centre, La Spezia Italy.

PUBLICATIONS

- [1] M. Siderius, M. Porter and C. Harrison, “An ambient noise fathometer for passive measurement of bottom depth and sub-bottom layering”, *Boundary influences in high frequency, shallow water acoustics*, edited by, Nicholas G. Pace and Philippe, Blondel, Bath, UK, 2005.
- [2] M. Siderius, C. Harrison and M. Porter, “A passive fathometer for determining bottom depth and imaging seabed layering using ambient noise”, *J. Acoust. Soc. Am.*, (Submitted).
- [3] M. Siderius and M. Porter, “A passive fathometer and sub-bottom profiler using ambient noise”, *J. Acoust. Soc. Am.*, **118**, No. 3, Pt. 2, September 2005 (A).

- [4] P. Nielsen, M. Fallat, S. Dosso and M. Siderius, "Measurements of weakly varying geoacoustic properties and their impact on acoustic propagation", *Proceedings of the International Conference "Underwater Acoustic Measurements: Technologies & Results"* Heraklion, Crete, Greece (2005).