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Sub-Bottom Profiling and Geoacoustic Inversion Using a Ship-Towed Line Array

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Introduction: Bottom properties in littoral water can be very complex (i.e., not horizontally stratified) and are location dependent, as indicated by core samples and seismic surveys taken in some areas. Acoustic signal propagation cannot avoid interacting with the bottom in shallow water areas. Navy operations in littoral regions require some knowledge of the signal propagation loss, which determines the range that a (distant) target can be detected. Knowing the bottom, thus, becomes critical for Navy operations in shallow water. Unfortunately, there exist few direct measurements of the ocean bottom except in some isolated locations, since core sampling and seismic measurements of the bottom are generally expensive and time consuming. Existing data bases often yield incorrect predictions of propagation loss because the data entries are sparse and neglect the variation of the bottom properties along the propagation path. A recent effort at NRL is devoted to developing an acoustic method to invert for the bottom properties (the geoacoustic inversion method) using a horizontal line array towed behind a ship. A ship can cover a wide area in a reasonable time (e.g., 24 km in 2 h). The towed array inversion method can provide snapshots of the bottom properties under the ship as it traverses an area, and in this way, build a data base for the Navy. This article summarizes recent advances made at NRL and experimental verifications of the method.^{1,2}

Sub-Bottom Profiling and Geoacoustic Inversion: Geoacoustic inversion correlates the signal calculated using an assumed bottom model with the acoustic data received on an array, and iteratively alters the parameters of the bottom (and other relevant parameters) until there is a good match between model and data. The method has been tested widely using vertical line-array data and works when there is some prior knowledge about the bottom, such as the number of sediment layers in the bottom. It is generally known that geoacoustic inversions can have ambiguous solutions, namely, that often more than one solution can fit the data. For building a database, the inversion method becomes untrustworthy if multiple data measurements of the same area yield different bottom profiles. Additional constraints, such as prior information, are needed to narrow down the inversion results.¹

In the seismic community, long horizontal arrays are used to survey the bottom using acoustic signals received from a distant source. Focusing on bottom

penetrating acoustic rays, the reduced ray travel time is deduced as a function of the ray arrival angle. This relationship can be used to determine the bottom layer thickness and bottom sound speed. In the acoustic community, geoacoustic inversion is preferred to seismic methods for two reasons: The towed sonar array is short compared with the seismic array, and the source-receiver range is fixed at a few hundred meters. The seismic community is interested in very deep bottom structure, whereas a shallow (sub-) bottom structure is more critical for sonar applications. The geoacoustic inversion method determines not only the bottom thickness and sound speed but also the bottom density and attenuation coefficients.

NRL developed a unified signal processing approach that combines a sub-bottom profiling method similar to that used by the seismic community with the geoacoustic inversion method used by the sonar community. By beamforming the towed array data, the beam outputs exhibit an angle and time (or depth) relationship (Fig. 3), from which one can extract a reduce-time-angle (or slowness) relationship similar to that used by the seismic community. Figure 3 shows a direct arrival from the source at an angle of approximately 5°, the surface-reflected arrival at approximately 18°, and bottom interacting arrivals at approximately 30°. The bottom arrivals show a return at the water-bottom interface and a return from the sub-bottom. The time difference is related to the sub-bottom thickness. Figure 4 displays the beam intensity time series at 30° for data collected over a 24-km ship track; this shows a sub-bottom layer structure (right figure) in good agreement with that obtained from a bottom profiler (left figure). The arrival angles and bottom-layer structure provide the needed inversion constraints to define sufficiently narrow parameter search windows, yielding an inverted bottom profile for water depth and sediment thickness, bottom-sound speed, and density and attenuation (Fig. 5). The inverted result at the edge of the track (designated as site 4) is in good agreement with an independent seismic reflection measurement conducted at site 4.

Summary: A method of geoacoustic inversion incorporating the information obtained from sub-bottom profiling is developed for a ship-towed line array. The sub-bottom profile data are deduced from the acoustic data and used to define parameter constraints used for geoacoustic inversion of the same data. The inversion result can be shown to be “unique” given the certainty of the bottom layer structure.² The method is being extended to use the ship’s own noise as the acoustic source. In this case, the acoustic ray arrival angles are used to constrain the parameter search windows and the inversion results.

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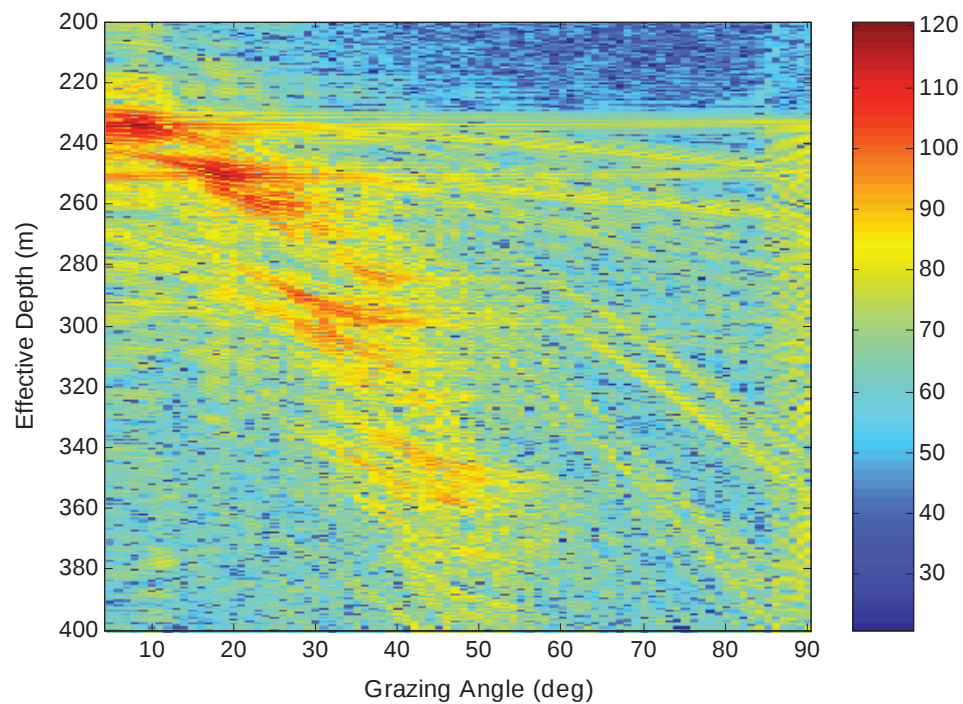


FIGURE 3
Beam-intensity time series at different beam angles measured from the forward endfire. Effective depth is travel time $\times$ 1582 m/s.

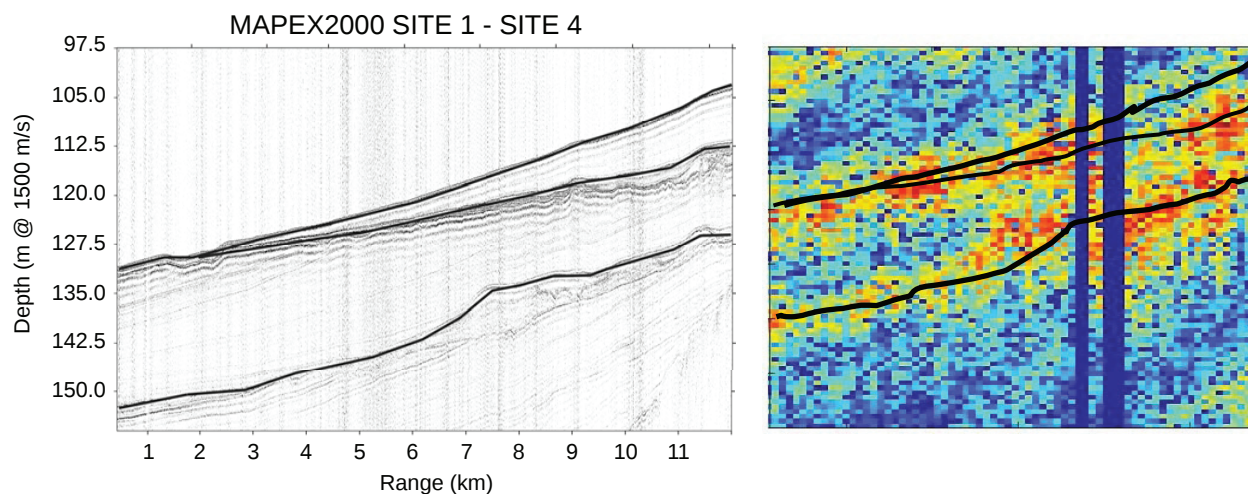


FIGURE 4
Effective depth determined from the bottom profiler (left figure). Effective depth estimated from the towed-array data superimposed with the profiler data.

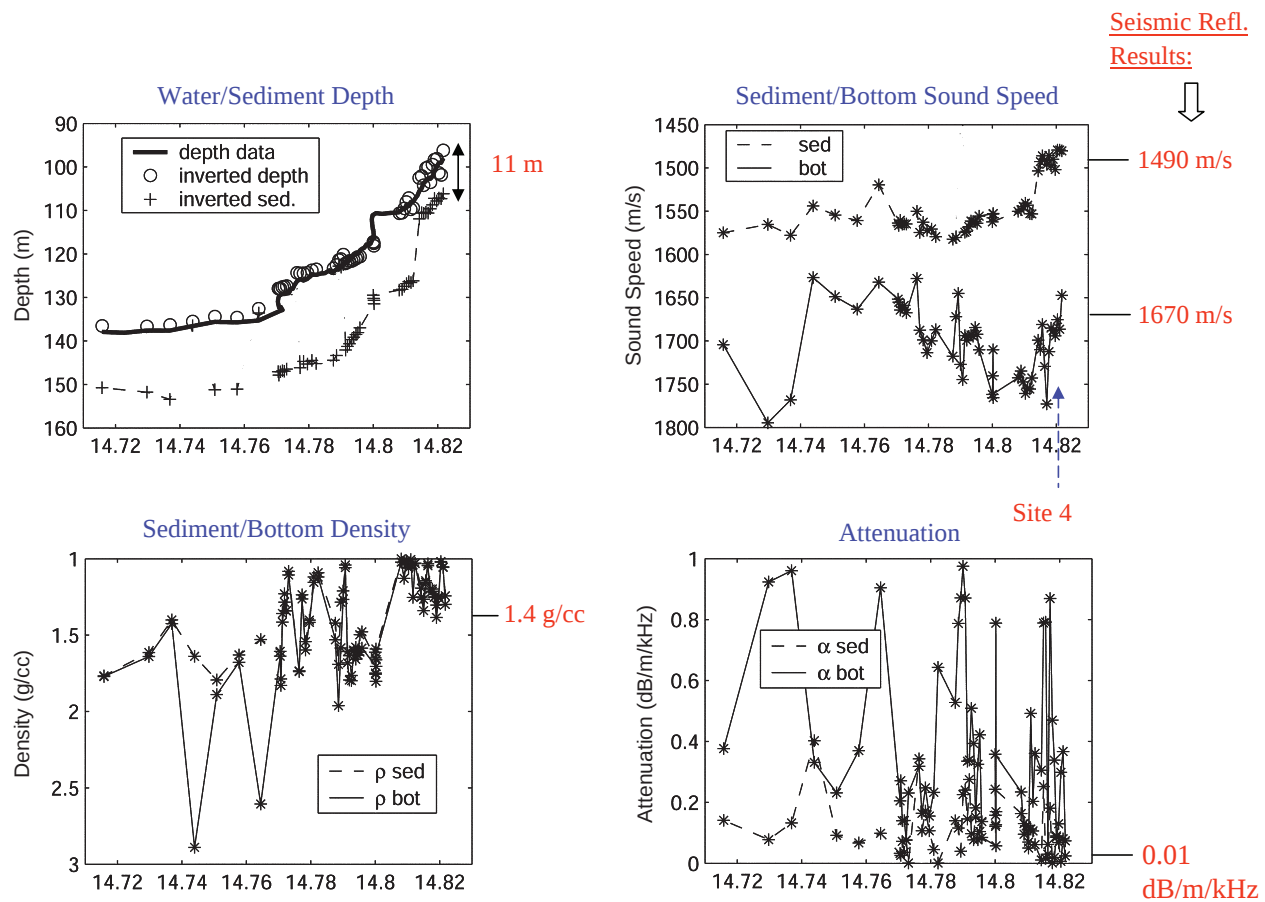


FIGURE 5

Geoacoustic inversion results for the water and sediment depth (upper left), sediment and bottom sound speed (upper right), sediment and bottom density (lower left) and sediment and bottom attenuation (lower right) along the track in longitude. The numbers on the right column are seismic reflection measurements at site 4.

References

¹ L.T. Fialkowski, T.C. Yang, K. Yoo, D.K. Dacol, and E. Kim, "Consistency and Reliability of Geoacoustic Inversions with a Horizontal Line Array," *J. Acoust. Soc. Am.*, in press.

² T.C. Yang, K. Yoo, and L. Fialkowski, "Sub-Bottom Profiling and Geoacoustic Inversion Using a Ship Towed Line," *Proceedings of Underwater Measurement and Technology Conference*, June 28–July 2, Crete, Greece (2005). ★