Inversion For Geoacoustic Model Parameters In Range-Dependent Shallow Water Environments

N. Ross Chapman
School of Earth and Ocean Sciences
University of Victoria
PO Box 3055
Victoria, B.C. V8W 3P6
phone: (250) 472-4340; fax: (250) 472-4620 email: chapman@uvic.ca

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LONG TERM GOALS

Our ability to predict acoustic fields in shallow water is limited by the knowledge of the structure and the geoacoustic properties of the bottom, both of which may change with range. The long-term objective of this research project is to investigate broadband matched field inversion methods for estimating geoacoustic model parameters and their uncertainties, in shallow water environments that may be range-dependent.

OBJECTIVES

Inversion for geoacoustic model parameters is set in the wider context of investigation of the effect of the ocean bottom on sound propagation. The need for information about geoacoustic parameters is critical for shallow water and littoral environments where the interaction with the ocean bottom plays a dominant role in sound propagation. Results from the 2001 SPAWAR/ONR benchmark workshop to assess the performance limits of present day inversion techniques for range dependent shallow water environments have demonstrated that there are several methods in use today that can provide accurate approximations for sound speed profiles in the bottom (Chapman et al., 2002). Our objective here is to implement new model-based (matched field) inversion methods that were tested in the workshop. The methods will be applied to data from the South Florida Ocean Measurement Centre (SFOMC) in order to estimate geoacoustic model parameters for the bottom at the SFOMC site. One of the inversion approaches makes use of a hybrid method for searching the model parameter space that greatly improves the efficiency of conventional formulations for matched field inversions. The other approach is based on ray acoustics to invert single hydrophone broadband data by modeling the signal waveform. Both methods are implemented as nonlinear optimization algorithms that provide simple and effective measures of the uncertainty of the estimated values. The performance of the inversions can be assessed against a good quality data set that is well ground-truthed.

APPROACH

The research proposed here makes use of data provided by Dr. H. DeFerrari that were obtained in a recent experiment carried out at the SFOMC site to investigate acoustic propagation at the site (Nguyen et al., IEEE JOE, 27, 235-244, 2002). In the experiment, M-sequence signals from 200-3200 Hz were transmitted from a source at 10 km range from a 32-element vertical line array. Preliminary analysis of the propagation characteristics of the waveguide suggest stable propagation channels for

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14. ABSTRACT
Our ability to predict acoustic fields in shallow water is limited by the knowledge of the structure and the geoacoustic properties of the bottom, both of which may change with range. The long-term objective of this research project is to investigate broadband matched field inversion methods for estimating geoacoustic model parameters and their uncertainties, in shallow water environments that may be range-dependent.

15. SUBJECT TERMS

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primarily water column signals with multiple bottom interactions, and for refracted signals that interact with the bottom at sub-critical angles. The first step in the research program is to carry out a simulation in order to fully understand the unique propagation conditions in the waveguide, using the environmental data from the experiment to calculate the pulse signal and the modal dispersion. Full-wave (normal mode and parabolic equation) and also ray propagation models will be used.

The next phase of the research is to apply newly developed matched field geoacoustic inversion techniques to the processed M-sequence data in order to determine the geoacoustic model parameters for the SFOMC site. Our inversion algorithm combines a local downhill method (Downhill simplex) with a simulated annealing global search technique (Musil, Wilmut, and Chapman IEEE JOE, 24, 358-369, 1999; Dosso, Wilmut and Lapinski, IEEE JOE, 26, 324-336, 2001). The algorithm is significantly more efficient than conventional simulated annealing for searching the model parameter space, and performs well in the presence of correlated model parameters. We will investigate a frequency subspace approach to estimate components of the geoacoustic profile. Normal mode propagation models will be used to invert the low frequency data (200 Hz), and ray-based methods will be used with the high frequency data to estimate sea floor properties.

Initially, only the low frequency data (200 and 400 Hz) will be inverted, using the normal mode approach. Since this method involves constructing a band limited signal, an interpolation method will be investigated for interpolating the modal wavenumbers over the frequency band.

The unique propagation characteristics of the waveguide at the SFOMC (Monjo and DeFerrari, JASA, 95, 3129-3148, 1994) site suggest that specialized techniques can be developed to invert the data. For the water column signals that propagate by multiple interactions with the surface and bottom, a method will be investigated based on modeling the intensity of each mode that can be identified in the signal pulse. These signals are the primary data on the array sensors that are shallower than the source depth. At deeper sensors, a second, stronger signal pulse is observed in conditions of strongly downward refracting sound speed profiles in the water. This signal is likely associated with sub-critical interactions with the carbonate bottom, and may be unique to this region. The modal dispersion that produces this signal can be inverted to extract geoacoustic parameters.

WORK COMPLETED

Acoustic data were received from H. DeFerrari in the form of processed envelope signals at the array for the M-sequence sound transmissions at 200 and 400 Hz. Environmental data consisting of the complete record of sound velocity profiles that were taken in the experiment were also sent. Our work concentrated on implementation of single channel inversions to make use of the envelope data. For this inversion, we assume that the waveguide is range independent, and use the normal mode propagation model ORCA to construct the signal envelopes for a frequency band of 50 Hz centered at the transmission frequency. Simulations were carried out to prepare for conventional matched field inversions that make use of the spatial phase information at the array. This approach is more suitable for application to the raw signal data.

RESULTS

Inversions based on the single channel data at 200 Hz have been carried out for the hydrophones in the bottom section of the array. The inversions make use of the adaptive simplex simulated annealing method to match the measured waveforms at the array hydrophones. This method provides a simple measure of the uncertainty in the estimated parameters, based on the variation of cost function values for the geoacoustic models that are searched in the inversion process.

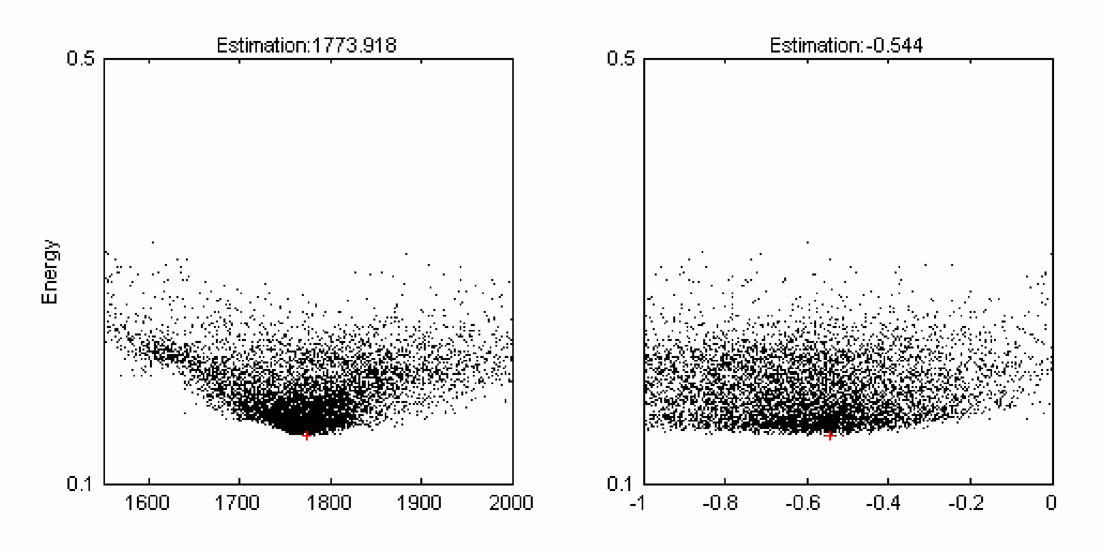

Figure 1. Inversion results for sound speed (m/s) and attenuation (dB/λ) for the 200 Hz data. The figures plot the cost function values for all the geoacoustic models searched in the inversion process.

The inversion searched for geometric parameters of the experiment (source range and source and receiver depths) and the geoacoustic parameters of a simple model of the bottom. The geoacoustic model consisted of a half space with unknown sound speed and attenuation; density was inferred from the sound speed and not estimated explicitly in the inversion. The estimates of the geometric parameters were close to the values reported in the experiment (DeFerrari, personal communication); they were included in the inversion as a simple check. The estimated values for the sound speed and attenuation are shown in Figure 1. The sound speed is consistent with the values expected for medium to coarse-grained sand that are found in shallow sediment cores in the region (DeFerrari, personal communication). The data in the figure show that the sound speed has been well estimated in the inversion. Attenuation is not as well estimated, as indicated by the relatively flat distribution of cost function values for the geoacoustic models that were sampled. Sensitivity to attenuation is likely derived from the long range geometry in the experiment. However, the value represents an average of the attenuation processes over the range. The estimated value is 0.54 dB/λ.

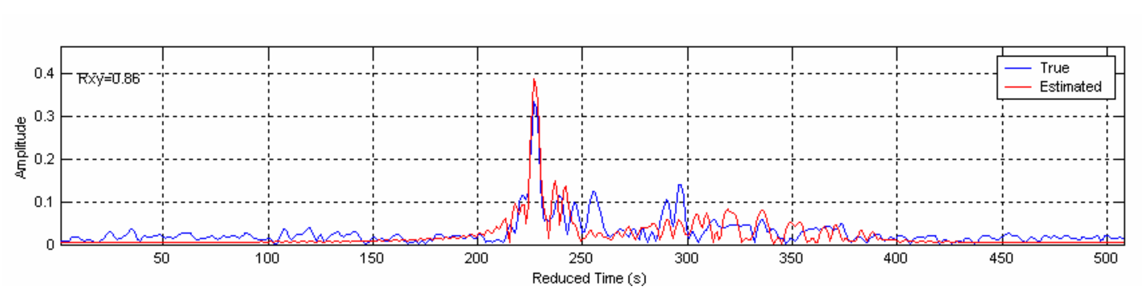

Figure 2. Comparison of the estimated and measured signal envelopes.

The modeled waveform using the estimated geoacoustic parameters is compared to the measured data in figure 2 for one of the M-sequence transmissions. The overall correlation is about 90 %. The main peak that is due to the refracted-bottom reflected energy in the deeper portion of the water column is well matched. The secondary peak that arises primarily from steeper angle propagation that samples the entire water column is not well modeled. The difference could be due to inaccurate water depth, or unknown range-dependent changes in sound speed or water depth.

IMPACT/APPLICATIONS

This project provides the opportunity to evaluate some of the approaches that were developed in the geoacoustic benchmark workshop. This issue was recognized as the next step in the geoacoustic inversion benchmark process. As a result of this work we will be able to assess the performance of hybrid full field inversion methods for estimating geoacoustic model parameters and their uncertainties, against data from a well ground-truthed ocean site.

The application with data from the Florida Straits provides a geoacoustic model for the SFOMC site. It will be therefore be possible to develop a more comprehensive understanding of the role of the ocean bottom in acoustic propagation at the SFOMC site.

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PUBLICATIONS

Chapman, N.R., S. Chin-Bing, D. King and R.B. Evans, Guest Editorial: Special Issue on Geoacoustic Inversion in range-dependent shallow water environments, IEEE Journal Oceanic Eng., 28, 2003 (in press).
Chapman, N.R., S. Chin-Bing, D. King and R.B. Evans, Benchmarking geoacoustic inversion methods for range-dependent waveguides, IEEE Journal Oceanic Eng., 28, 2003 (in press).

HONORS

N.R. Chapman elected Senior Member of the Institute of Electrical and Electronic Engineering, June 2003.