

Inversion for Geoacoustic Model Parameters in Range-Dependent Shallow Water Environments

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Shallow-water acoustics

LONG TERM GOALS

Our ability to predict acoustic fields in shallow water is limited by knowledge of the parameters of geoacoustic models that are used to describe the interaction with the ocean bottom. The need for information about geoacoustic profiles is critical for shallow water and littoral environments where the interaction with the ocean bottom plays a dominant role in sound propagation. The long-term goal of this research 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

Our objectives in this research are related to the overall objectives of SW06, an ONR-supported, multi-purpose underwater acoustic sea trial carried out recently on the New Jersey Shelf. Experiments were designed in SW06 to acquire data for geoacoustic inversion in range-dependent environments, and to investigate the physics of sound propagation in marine sediments over a wide frequency range from 50 Hz to several 10s of kHz. In preparation for the experiments, a canonical geoacoustic model was generated for the site, using available ground truth information. The focus of the research reported here was to investigate the performance of matched field inversion methods for estimating geoacoustic profiles in the SW06 environment. Specific objectives were: (1) assess the validity of the canonical geoacoustic model for use in range dependent environments; (2) determine the impact of three-dimensional propagation effects on inversions in along-shelf propagation geometries; and (3) investigate the use of long-range experimental geometries in estimating sediment attenuation.

APPROACH

The approach taken in this research was to make use of broadband air gun data from the SWARM95 experiment (Apel et al., 1997) that was carried out in the vicinity of the designated SW06 site. This option provided a means to evaluate inversion performance in real conditions that were characteristic of the experimental site. The air gun data were recorded on a 16-element vertical array, for fixed-range, along-shelf experimental geometries of ~ 5 km source/receiver distances. The bathymetry was weakly range dependent, varying from 71-73 m over the propagation path, and the cross range sea floor slope was less than 1° . Also, the experiments were done at a time when no internal waves were detected in the propagation path by the SWARM95 environmental monitoring system. These conditions provided a benchmark environment for geoacoustic inversion in which the effects of

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unknown time and spatially varying inhomogeneities in the water column and horizontal refraction due to bottom interaction were not expected to be significant.

A total of 131 shots at 25-m source depth and 80 shots at 45-m source depth were used in the inversions. The data were processed to obtain the air gun shot spectra. The useful range of frequencies for which the signal-to-noise ratio was greater than 10 dB was 30-200 Hz. Inversions were carried out in two frequency bands, 30-90 Hz and 110-190 Hz, using five frequencies in each band. The spectral components for each inversion were selected on the basis of high spatial coherence across the array. An example of the spectrum and the measured coherence for one of the 25-m shots is shown in Figure 1.

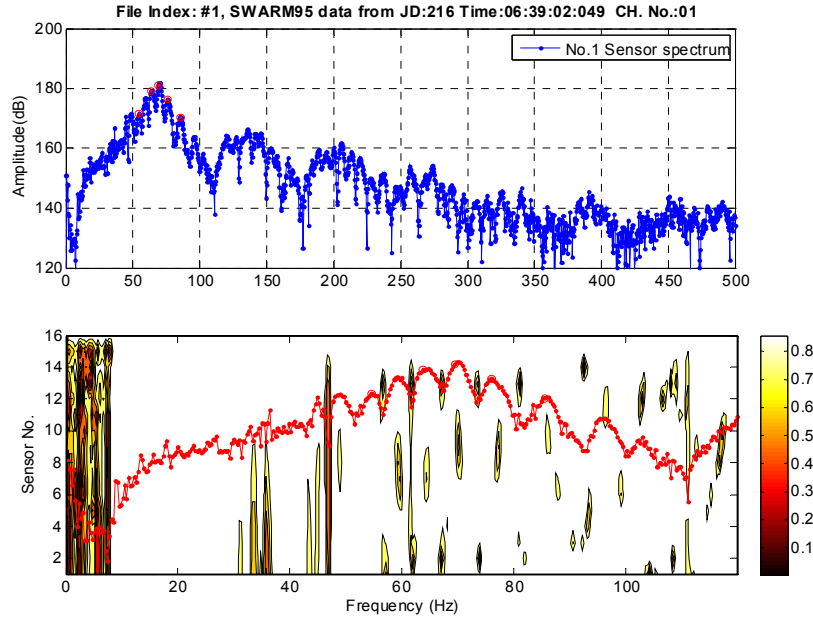


Figure 1. (upper) Spectrum of 45-m shot on channel 1 of VLA. (lower) Spatial coherence plotted vs frequency for all the array channels. The white sections over all channels indicate high spatial coherence.

The inversion was based on a multi-frequency Bartlett cost function that was processed incoherently, combined with the hybrid search method, Adaptive Simplex Simulated Annealing (ASSA), (Musil, Wilmut, and Chapman, 1999; Dosso, Wilmut and Lapinski, 2001) to navigate the model parameter space. This algorithm provides a simple measure of the sensitivities of the model parameters. A histogram of the optimal estimates was generated from the ensemble of shot data for each source depth to indicate the parameter sensitivity and to provide a measure of the uncertainty for the estimated values.

WORK COMPLETED

The high resolution canonical geoacoustic model shown in the upper panel of Figure 2 was generated for use by researchers in preparations for the SW06 experiment, and was presented at the SW06 workshop in Minneapolis MN (Chapman, 2006). The model was derived from available ground truth information, and was intended for use over the full range of frequencies in the experiment. For the air gun data inversions, a low-frequency two layer approximation of the multilayer model was used to parameterize the ocean bottom (shown in the lower panel of Figure 2). The inversions estimated the

layer thickness, sound speed, attenuation and density of the single sediment layer and the basement half space, and the range, water depth and source depth.

Acoustic data from the SWARM95 experiment were received from Dr. Mohsen Badiy (University of Delaware) in the form of unprocessed pressure signals at the array. Environmental data consisting of sound velocity profiles that were taken in the experiment, and information about the experimental geometry were also supplied. Geoacoustic inversions were carried out for all of the shots in two low frequency bands, one from 30-90 Hz centered at ~65 Hz, and the other from 110-190 Hz centered at 150 Hz.

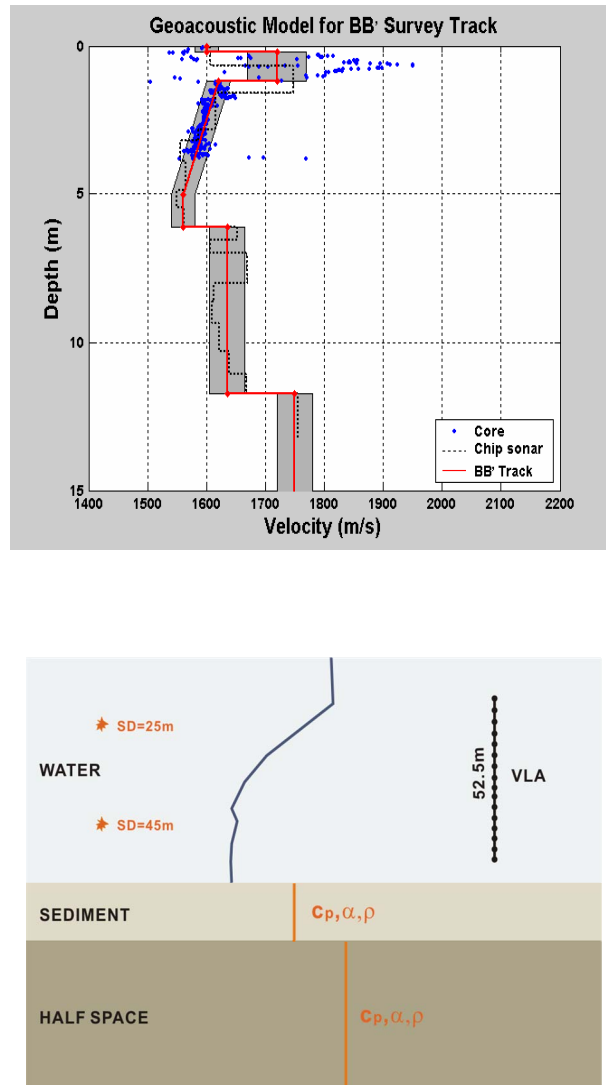


Figure 2. (upper) High resolution geoacoustic model of the SW06 experimental site. (lower) Low frequency approximation to the geoacoustic model.

RESULTS

The optimal estimates from the inversion are shown in Figure 3 as histograms of the estimated values over the set of shots. From the spread of values in the histograms we can infer that: 1) Source depth, SD, water depth, WD, and sediment p-wave sound speed, c_{p1} , are very well determined with small variance. The range is also well estimates, but since the range is varying during the The values of the geometrical parameters are very close to the known values from independent measurements in the experiment; 2) P-wave attenuation of the sediment is well estimated also, although the relative uncertainty is larger compare to that for SD, WD and c_{p1} . The p-wave attenuation estimates for both frequency bands at the two different source depths are consistent. Moreover, the mean values of the estimates at the higher band are approximate twice as large as those for the lower band, for both source depths; 3) Sediment density is not as well estimated as sediment p-wave attenuation; 4) Sediment depth, H, is not well determined. For both source depths, at the lower frequency band the mean values of the estimate are deeper, while at higher frequency band they are shallower; 5) P-wave sound speed, p-wave attenuation and density for lower half space are not resolvable in the inversion.

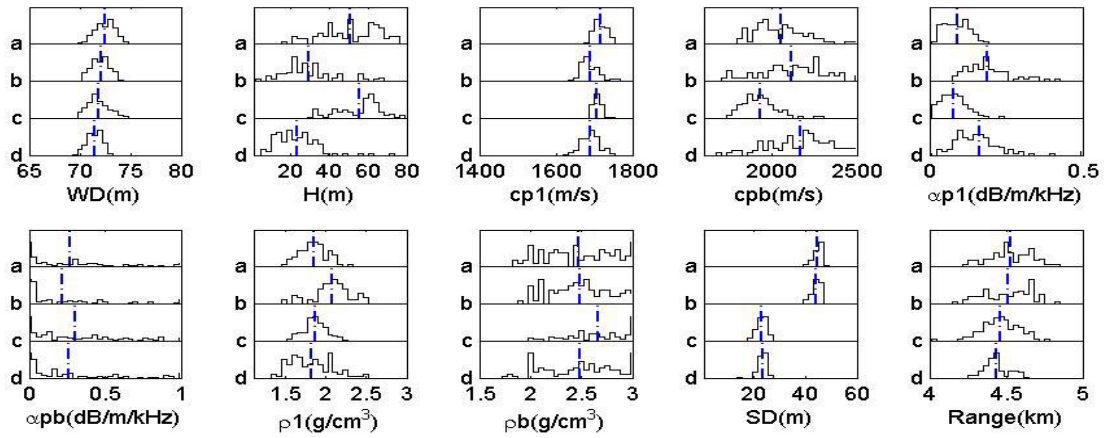


Figure 3. Histograms of the estimated values for the geoacoustic and geometric parameters. Rows a and b show the results for the lower and higher frequency band for the 25-m shots, and rows c and d show the results for the lower and higher frequency band for the 45-m shots

The inversion results can be explained in the context of the long-range experimental geometry. Sound propagation for both source depths is primarily by low-angle bottom interacting paths for which the grazing angle is less than critical, according to the estimated values for the sediment sound speed. In this case, the sound field in the bottom is evanescent, so there is only very weak interaction at depths greater than about one wavelength. According to the high resolution model, the weighted p-wave sound speed for the 4 layers down to about 20 m is 1703 m/s and the mass density is 1.986 g/cm³. These averaged values are very close to the estimated values for the low frequencies used in this inversion.

Notably, the inversion was sensitive to the sediment attenuation, and the estimated values indicated an approximate linear change between the two low frequency bands. The estimate represents an averaged result over about a wavelength in depth below the sea floor interface; the value obtained is likely related to the different depth penetration for each frequency band. Although sensitivity to

attenuation was increased, the long-range, low-angle propagation geometry did not enhance sensitivity to the sediment shear wave parameters.

IMPACT/APPLICATIONS

The project demonstrated several issues connected with the design of experiments for investigating the interaction with the ocean bottom and for inversion of geoacoustic model parameters. The lessons learned have been applied in the workshop planning sessions for the ONR Shallow Water experiment:

- The high resolution geoacoustic model developed in this project provides an effective description for the New Jersey shelf environment in the vicinity of the SW06 experimental site for applications at low frequencies (< 200 Hz).
- The broadband air gun signal transmissions provide good quality data for use in geoacoustic inversion.
- The long-range experimental geometry provides sensitivity for estimating attenuation, but not shear speed, by inversion of acoustic field data.
- Although all present day methods have not been tested against a common experimental data set, inversion methods based on matched field processing that were benchmarked in the ONR benchmark workshops are capable of estimating realistic geoacoustic models from the experimental data. Data from this experimental site could provide a suitable benchmark test case.
- Overall, inversions from shorter range geometries should be combined with the long range data inversions to obtain information about deeper layers in the sediment.

RELATED PROJECTS

- The project was a collaboration with Dr. M. Badiy of U. of Delaware.
- The high resolution geoacoustic model was shared with all the other researchers in their preparations for the ONR SW06 experiment.
- Geoacoustic inversion experience and expertise is shared in collaborations with A. Tolstoy, P. Gerstoft and W. Hodgkiss, D. Knobles, and P. Dahl and D.J. Tang.
- The project provided the opportunity to evaluate some of the approaches that were developed in the ONR-sponsored geoacoustic benchmark workshops against real data, an issue that was recognized as the next step in the geoacoustic inversion benchmark process.

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HONORS

N.R. Chapman was elected Chair of the Technical Committee on Acoustical Oceanography of the Acoustical Society of America, 2004-2007, and became an Associate Editor of the IEEE Journal of Oceanic Engineering in 2006.