Inversion of Shot Data for Oceanographic Fields and Sediment Parameters in the Shelf Break PRIMER Experiment

James H. Miller
University of Rhode Island
Department of Ocean Engineering
Narragansett, RI 02882
phone (401) 874-6540 fax (401) 874-6837 email miller@uri.edu
Award Number: N000149810058

LONG-TERM GOALS

Our long term objective is to develop an inversion scheme for the estimation of acoustic properties of sediments in shallow water using broadband explosive sources.

OBJECTIVES

- Develop an inversion scheme based on modal dispersion of broadband acoustic data from explosive sources.
- Apply this inversion scheme to range dependent and mildly range dependent environments in the continental shelf areas of New England Bight.
- Explore the effectiveness of different nonlinear optimization techniques to develop efficient and robust hybrid schemes for the inversion scheme.
- Provide quantitative estimates of resolution and variance along with the inversion results.
- Explore the possibility of using the data from range dependent environments to invert a simple two layer model of the bottom.

APPROACH

When a broadband source such as an explosive charge is used to generate acoustic energy in a shallow water wave guide, the acoustic propagation exhibits dispersion effects. Group speeds, i.e., the speeds at which energy is transported, vary for different frequencies and modes. This dispersion behavior can be utilized for the inversion of bottom properties.

The data used for this study was collected during the Shelf Break Primer Experiment (PRIMER) conducted during the summer of 1996. Acoustic signals from the explosive sources were collected at two vertical line arrays (VLAs) located in the continental shelf at approximately 90 m of water. Explosive charges consisting of 1.8 lbs. of TNT were dropped in the continental shelf as well as in the slope in water depths varying from 90 m to 300 m and were set to explode at a depth of 18 m. The VLA at the northeast corner of the experimental area consisted of 16 hydrophones which span the lower half of the water column from 45 m to 90 m. Data was acquired with sampling frequency of 1395 samples/sec. In order to compare and validate the inversion, gravity cores were taken at six locations (four in the shelf and two in the slope) during early 1999. These cores were logged at the Marine Geomechanics Laboratory at University of Rhode Island to obtain the sediment compressional speeds and attenuation. These gravity cores penetrate only 1.5 m to 2 m into the sediment. Another

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deep core in the slope at nearly 300 m of water (Atlantic Margin Coring Project) provided the data for comparison in the deeper depths.

The time series of the acoustic pressure recorded on the VLA was analyzed to extract its time frequency behavior using wavelet based methods. A Morlet wavelet was used to generate the dispersed arrival patterns of various modes. The arrival times corresponding to various identifiable modes at different frequencies were peak picked. This data was used in the inversion scheme to determine the compressional speeds. The mode amplitudes also were calculated in order to find the amplitude ratios. This data was used to estimate the modal attenuation coefficients.

Genetic Algorithms (GAs) were used as the primary tool to implement the inversion scheme. GAs are nonlinear optimization schemes, highly efficient in optimizing discontinuous, noisy, highly dimensional and multimodal objective functions. In this study GA was used to minimize the cumulative mismatch between the experimental travel time data for different modes and frequencies and the theoretical estimates. GA was used to generate and improve a set of parameters which were used to calculate these theoretical estimates. The sound speed in the water column modeled using Empirical Orthogonal Functions (EOFs), sediment speeds at various depths, depth of water and range comprised of the parameter set in the range independent case. A sensitivity study was performed to estimate the effect of variation in each of these parameters on the calculated group speeds. For each set of parameters that GA generate, the sound speed model was constructed using these values and the corresponding arrival times were calculated using a normal mode routine. In the adiabatic case, which is suitable for mildly varying environments, the range was divided into segments of range independent regions. The ocean sound speed and depth of water were assumed to vary from segment to segment while the sediment properties were assumed constant. Hence EOF coefficients and water depth at each segment together with sediment compressional speeds at different depths and range formed the parameter set in this case.

The inversion scheme for attenuation is based on minimizing the mismatch between the observed modal amplitude ratios and the predictions (Zhou and Zhang) [1]. Prediction is based on normal mode approach and using the results of the compressional speed inversion. The estimated transmission loss (TL) using the modal attenuation coefficients was compared with the actual data. The attenuation profile can be computed from the modal attenuation coefficients using linear inverse theory.

One major disadvantage of inversions using global optimization methods is the extensive computational efforts involved in evaluating the '‘fitness’ of each parameter set in every step of the GA. Hybrid schemes incorporate the use of another method in combination with the GA in order to hasten the optimization process. Levenberg-Marquardt technique, Differential Evolution method and neighborhood algorithms were used in conjunction with the GA to develop an efficient hybrid scheme. Levenberg-Marquardt technique is a local optimization scheme wherein local gradient and curvature information is utilized to march towards the local minimum. In the Differential Evolution method new parameter sets are evaluated using the existing ones using special operators (Storn and Price [2]). Neighborhood algorithms are derivative–free search methods, which make use of geometric constructs known as Voronoi cells ([Sambridge [3]). These are nearest neighbor regions defined under a suitable distance norm. These methods will be used to modify the inversion algorithm using the GA and their performance will be compared and assessed.

Resolution and variance were computed using different approaches. One approach is to use linear perturbation methods (Lynch *et al*. [4]) which provide resolution in depth and variances. These perturbation approaches break down the nonlinear problem into a linear one near the vicinity of the solution. Hence an accurate initial guess for the environment is required for getting good estimates. The results obtained using the GA inversion can be used as a background profile for this purpose. By applying the perturbation method we can improve the sound speed profile estimates and also compute resolution and variances.

A posteriori error estimates can also be computed using the approach popularized be Sen and Stoffa [5] and Gerstoft [6]. In this approach all the parameter sets and their ‘fitnesses’ generated by the GA will be stored. These fitnesses will be used to calculate the probability density of each parameter set. Using these probability densities the *a posteriori* mean and covariances can be computed. In addition to this locally defined error bounds can be obtained by using the Hessian matrix. Hessian matrix can be computed as the second partial derivatives of the error surface with respect to each parameter. The curvature of the error surface is an indicator of the narrowness of the peak (or valley) of the error surface in the vicinity of the solution. *A posteriori* resolution is computed by a method suggested by Parker [7] where a perturbation in the form of a Gaussian of known amplitude and width is introduced into the sound speed model. The width of the output Gaussian is an indicator of the resolution at the depth where the perturbation is introduced. The data corresponding to the perturbed sound speed profile has to be synthetically generated.

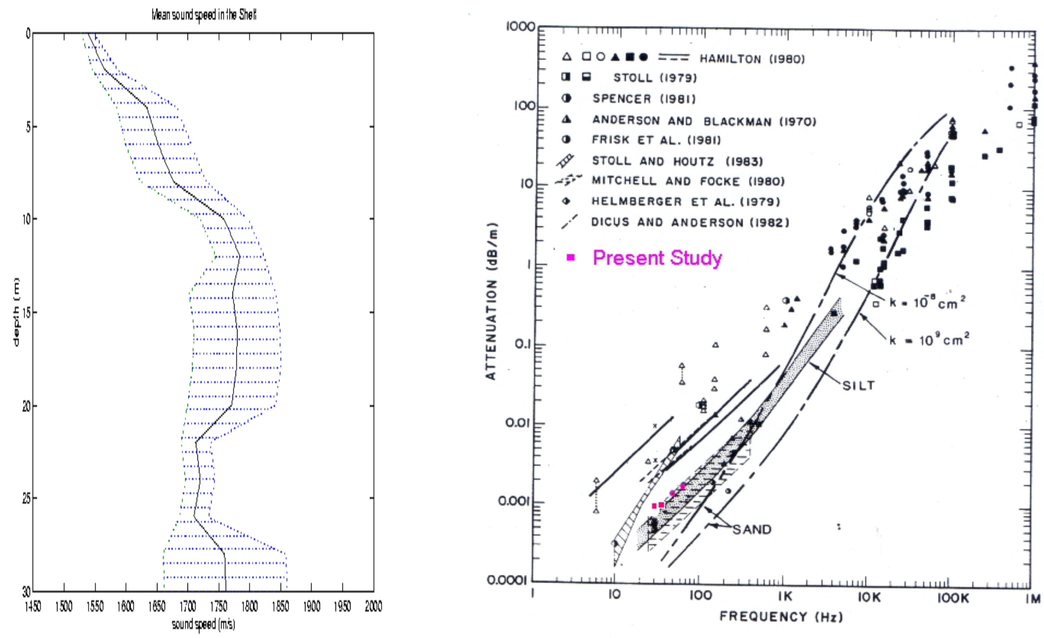
Propagation of acoustic energy from the explosive sources in the slope region upslope to the VLA is complicated compared to the shelf region. The varying bathymetry and the presence of the shelf break front and the possibility of a range varying bottom introduces range dependence in the propagation. The travel time will be computed using the approach introduced by Desaubies *et al*. [8]. They have provided solutions to the coupled mode equations using asymptotic expansions. Modal phase will be calculated by including the coupling terms. These coupling terms will be significant when the horizontal variability in sound speed is high. Since the computational effort involved in range dependent modeling is very high compared to adiabatic model only a simple two layer model for the bottom will be inverted.

WORK COMPLETED

The inversion scheme has been successfully implemented to estimate the compressional speed profiles in the continental shelf region using adiabatic theory. Inversions were performed using SUS charges at different locations in the shelf. The attenuation coefficients were also estimated and compared with the gravity core data. Hybrid schemes using Levenberg-Marquardt method, Differential Evolution and neighborhood algorithms were implemented. Resolution and variance for the inversion also were provided.

RESULTS

Left panel in the Figure 1 shows the mean compressional speed profile in the shelf region. This was obtained by performing the inversion on a number of SUS charges deployed at different locations in the shelf. The shaded region indicates one standard deviation on either side of the mean. The right panel shows the attenuation coefficient in dB/m obtained by the present study along with historical data.



Mean compressional speed profile in the shelf. The shaded region covers standard deviation on either side of the mean.

Attenuation estimates (dB/m) obtained from present inversion. This figure is taken from Stoll (J.Acoust. Soc. Am., V 77 (5), (1985).

Figure 1. Mean compressional speed profile and attenuation coefficient estimates in the shelf region.

IMPACT/APPLICATIONS

This inversion scheme using explosive sources is suitable for rapid estimation of acoustic properties of sediments in shallow water. Usefulness of this method is further enhanced by the low cost involved since a single hydrophone together with air deployed explosives can provide the data for inversion.

TRANSITIONS

The sediment parameters obtained by the inversion are being used for the propagation modeling efforts at WHOI.

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