Geoacoustic Inversion for Spatially and Temporally Varying Shallow Water Environments

ONR Special Research Awards in Underwater Acoustics: Entry Level Faculty Award

Kyle M. Becker
The Pennsylvania State University/Applied Research Laboratory
State College, PA 16804-0030
Phone:(814) 863-4159 Fax: (814) 863-8783 E-mail: kmbecker@psu.edu

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LONG-TERM GOALS

The long-term objective of this work is to develop methods for rapid assessment of seabed variability combined with detailed localized geoacoustic inversions to characterize the bottom for a given shallow-water environment. Consideration will be given to spatial and temporal variability in the watercolumn properties common to shallow-water environments and their impact on inversion results. Methods will be developed in recognition of Navy needs for Rapid Environmental Assessment (REA) in littoral regions and corresponding interests in Intelligence, Surveillance, and Reconnaissance (ISR), Anti-Submarine Warfare (ASW), and Mine Warfare (MIW).

OBJECTIVES

The goals of this project are to develop improved methods for extracting physical seabed parameters in shallow water. Methods will be developed using modal content and dispersion of acoustic fields to determine range dependence in the sediment structure and to construct background models for either linear (perturbative) or non-linear geoacoustic inversion methods such as those based on genetic algorithms (GA) or simulated annealing (SA).

APPROACH

The approach is based on the analysis of both simulated and measured data representing a variety of geoacoustic environments. Emphasis is placed on parameter extraction for environments with spatially varying sediment and water column properties using both broadband and cw data spanning 50-300 Hz. Data to be analyzed were collected as part of the ONR sponsored Shallow Water Experiment 2006 (SW06).

As part of SW06, this work was done with the collaboration of scientists and engineers from the Woods Hole Oceanographic Institution (WHOI), Scientific Solutions Inc. (SSI), University of Washington (UW), and Florida Atlantic University (FAU). Subramaniam Rajan helped plan the individual experiments. (SSI) Jim Lynch and Arthur Newhall (WHOI) supported acoustic data collection on the WHOI Shark array and single channel recording units. George Frisk (FAU) rented a J-15-3 source for his experimental component of SW06 and provided it for this work. Keith von der

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Heydt, Calvert Eck, and John Kemp (WHOI) provided engineering and technical support for deploying the J-15 source from the R/V Endeavor. Cynthia Sellers (WHOI) provided logistics support for operating the J-15. Frank Henyey and Kevin Williams (UW) collaborated on towed CTD chain operations for these experiments. Megan Ballard, H. John Camin, and Joy Lyons, graduate students in the Penn State Graduate Program in Acoustics, participated in the experiment and will analyze data for their respective dissertations. In addition graduate students Jacquie Beitel (University of Rhode Island) and Inga Koszalka (Politecnico di Torino –Turin, Italy) along with undergraduate student Amanda Dye (University of Michigan) volunteered and participated in data collection during the SW06 sea trial.

To infer range-dependent bottom properties in shallow-water waveguides, a set of acoustic experiments were designed and implemented during SW06. The data collected are intended for use in linearized methods using the modal content of propagating acoustic fields as input data to the inversion algorithms. The experiments were designed to investigate inversion methods capable of accounting for range-dependence in the seabed that is both measurable, such as bathymetry, and unknown, such as that due to intrusions or layer pinching. Specific research areas to be addressed include continued investigation of high-resolution wavenumber [1] and modal estimation techniques, understanding the impact of watercolumn variability on wavenumber estimation [2][3], and exploring new methods for removing the effects of bathymetry on the measured acoustic fields, as in [4]. In addition, inversion methods based on modal dispersion will also be explored. Modal dispersion will be examined for both broadband pulses and for a comb of cw tones for moving sources [5,2]. Modal dispersion in the latter case was observed for 50 Hz data during the October 2000 Shallow Water Acoustic Technology (SWAT) experiments (Chief Scientist Robert Field, NRL). Based on the observations, a method was devised for inferring modal group velocities from measurements of the shift in horizontal wavenumbers for a moving source [6][7].

Specific experiments were designed and executed during SW06 to test the ideas stated above. A J-15-3 low frequency sound source was used for all experiments. The primary receivers were the WHOI Shark array. To create synthetic apertures for horizontal wavenumber processing, the source was towed along radials from the WHOI VLA. The experiments were designed to measure modal dispersion by towing the source at different speeds along the radials. For these runs, a comb of constant wavelength tones was transmitted at 50, 75, 125, and 175 Hz. Modal dispersion experiments for broadband signals were designed to use a 250 Hz linear FM sweep starting at 40 Hz. The sweeps were 0.5 s duration and repeated every 3 seconds for the source 15 km from the WHOI VLA. 6 minutes of data were collected for points around a circle at the 15 km stand-off distance from the array.

In addition to the acoustic data, detailed environmental data was collected using a towed CTD chain system. The towed CTD provides a detailed spatial/temporal look at the temperature/salinity and corresponding sound speed field in the water column. Experiments conducted during SW06 were designed to have the towed CTD system deployed during all source operations.

WORK COMPLETED

The experimental work proposed for SW06 was completed during this year. During the experiment, this project was allocated 36 hours (12 hours each day 4-6 August, 2006) for acoustic transmissions. At the conclusion of the experiment, 34 hours of data were collected. Over 24 hours of towed cw data were collected along 3 different radials. Tow speeds ranged between 2 and 10 knots. The remaining data were LFMs. LFM data were collected for over 25 different stations on a circle 15 km from the VLA. The acoustic data is currently being backed up and archived for distribution by WHOI. In addition to the acoustic data, towed CTD data was collected concurrently during all transmissions. For the towed geometries, the data yield the spatial sound velocity structure over the propagation path at the source location. For the LFM stations, the towed CTD data gives the temporal variability of the sound velocity profile at the source location.

RESULTS

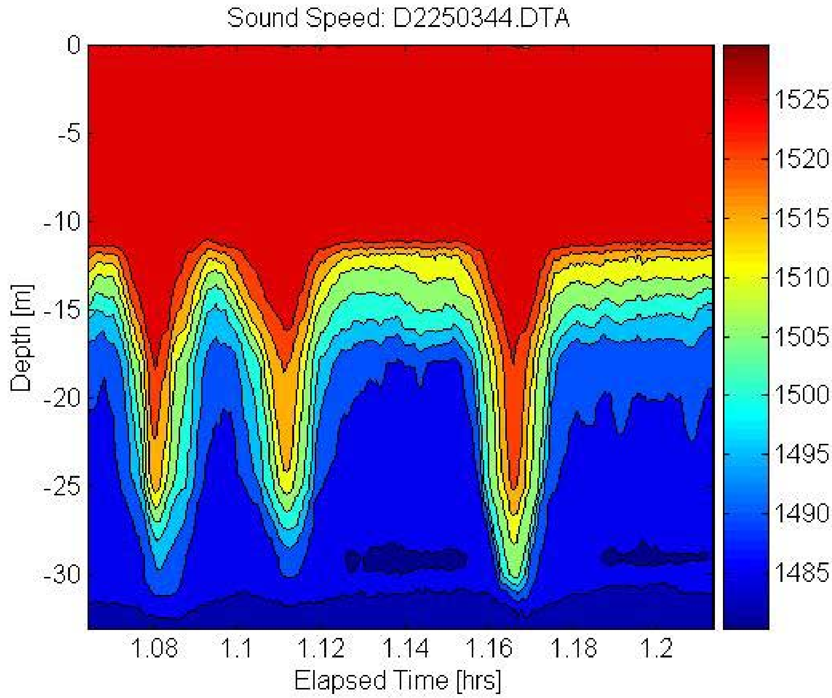

Fig. 1 Representative sound velocity field derived from towed CTD chain data with internal waves present.

Figure 1 illustrates data from the towed CTD chain converted to the sound velocity field in time and depth. The plot indicates a leading solitary wave followed by a train of internal waves. Data of this type were collected during all acoustic transmissions for these sets of experiments. Additionally, towed CTD data were collected for an additional two weeks while working with Frank Henyey. Internal waves were predicted based on the tidal cycles and the ship positioned to intercept waves as they were generated and propagating up the slope. Ship radar and sea surface observations were used to locate internal waves. When located, the CTD chain was repeatedly towed across an internal wave packet as it propagated up the shelf. Detailed data, as in Fig. 1, were collected for a number of individual internal wave events.

In addition to the experimental data, preliminary numerical modeling studies were conducted in anticipation of SW06. One such study was to gain an understanding of the acoustic field measured on a synthetic aperture horizontal array when a propagating internal wave field is present. The modeling results indicate that the acoustic field measured by a moving receiver samples all the relevant peaks and nulls in the field as created by the interference of propagating normal modes. This is indicated in Fig. 2 where the wavenumber spectrum of the synthetic aperture sampled field is shown in blue plotted along with the spectrum for the acoustic field created using a single sound velocity profile (or no internal waves).

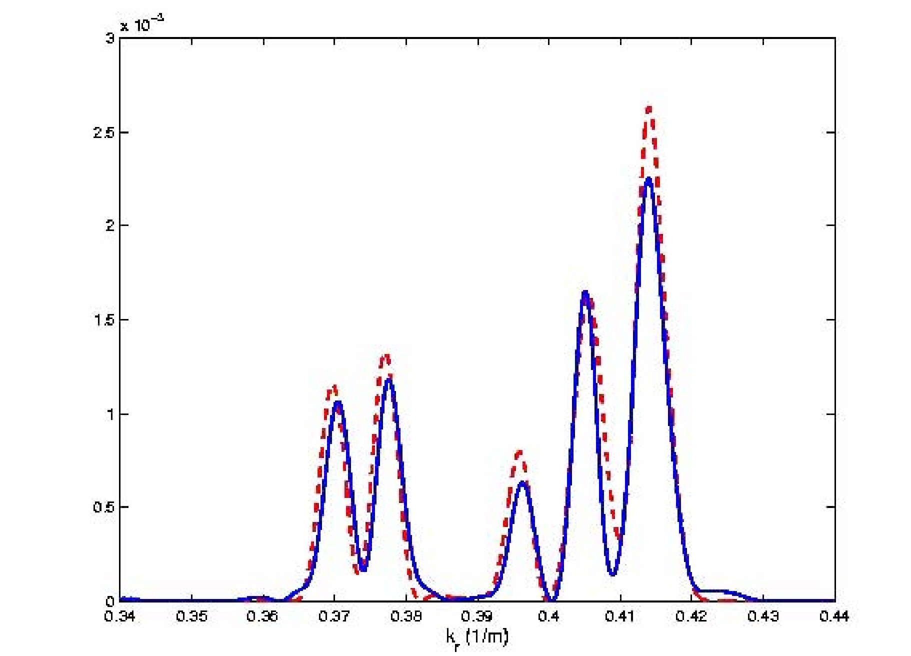

Fig. 2. Horizontal Wavenumber spectrum for synthetic aperture field measures with internal waves (blue) and for a single sound speed profile from the measured set (red dashed)

IMPACT/APPLICATIONS

The application of these results is for geoacoustic inversion in range-dependent shallow water regions. The results suggest ways to account for and deal with the variability inherent in the watercolumn in shallow regions. In addition, the high-resolution methods reduce the apertures required to extract modal information resulting in more localized inversion results.

RELATED PROJECTS

This work was a component of SW06. The approaches being developed recognize the complexities of shallow water waveguide environments and seek to account for them. Data and results from these experiments will be shared with and compared with those of other participating PIs. In addition, it is anticipated that the towed CTD chain data will prove invaluable to interpreting results from this experiment and prove itself to be a worth took for consideration in other upcoming experiments, such as the uncertainty DRI.

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