Accounting for Ocean and Seabed Variability in Oceanic Waveguide Parameter Estimation

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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 shallow-water environments. Consideration is given to spatial and temporal variability of water column properties common to shallow-water environments and their impact on inversion results. Advances made in the work will contribute to development of unified ocean/ seabed/ acoustic models and improved prediction capabilities for USW tactical decision aids.

OBJECTIVES

The objective of this research is to expand our understanding of propagation in shallow waters by incorporating high-resolution measurements of both the acoustic field and the ocean environment. The immediate goals of the proposed work are to address research issues relating to parameter estimation derived from acoustic field measurements in shallow water. Parameters of interest include seabed properties (sound speed, density, attenuation) and morphology along with source location. Issues to be addressed include: parameter estimation for geospatially varying bathymetry and sediments; the impact of water column variability on geoacoustic inversion; and the effects of Doppler shift in a waveguide on acoustic measurements and inversion. A particular goal is a comparison of inversion results based on modal eigenvalue estimates and modal dispersion obtained using different co-located data sets.

APPROACH

The approach is focused on analysis of both low-frequency acoustic and high-resolution oceanographic data collected during the Modal Inversion Methods Experiments (MIME) during August 2006[1]. MIME was conducted as part of the ONR Shallow Water 06 (SW06) experiment. Acoustic data were collected along synthetic apertures created by a towed source emitting low-frequency, continuous wave (cw) tones (50,75,125, and 175 Hz) and for a stationary source transmitting a broadband signal with 250 Hz bandwidth. The acoustic data were measured on a fixed combined vertical/horizontal line array. The towed source experiments were designed to exploit Doppler shift in a waveguide to extract modal group velocity information. The 50 Hz acoustic pressure field measured at a single depth on the receive array for different tow speeds toward and back along a radial are shown in Fig. 1, with unwrapped phase in the lower panel. For synthetic aperture pressure fields transformed into wavenumber space corresponding modal eigenvalue shifts depend on modal group velocity [2].

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14. ABSTRACT

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 shallow-water environments. Consideration is given to spatial and temporal variability of water column properties common to shallow-water environments and their impact on inversion results. Advances made in the work will contribute to development of unified ocean/ seabed/ acoustic models and improved prediction capabilities for USW tactical decision aids.

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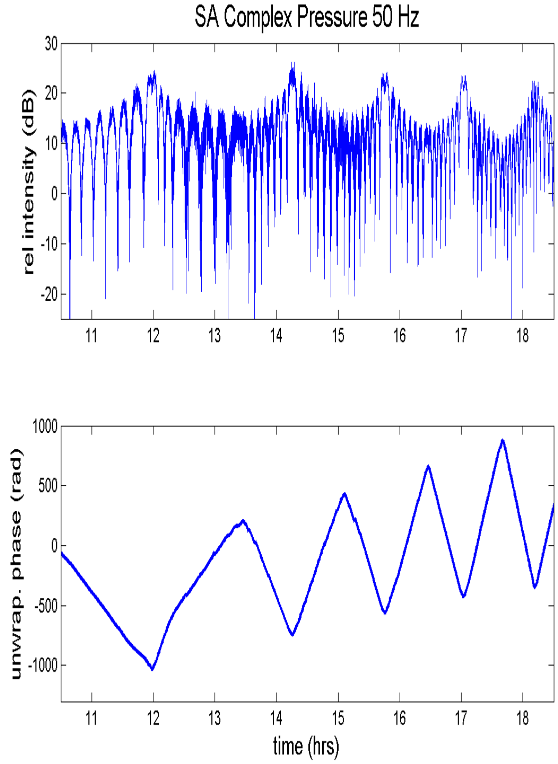

Fig. 1 Pressure field (50 Hz) measured at a single depth on the receive array. Top panel is magnitude and bottom panel unwrapped phase.

Analysis of the SW06 data seeks solutions to the geoacoustic inversion problem which are optimized for both efficiency and accuracy. Emphasis will be placed on developing methods capable of accounting for range-dependence in the seabed that is both directly measurable, such as bathymetry, and unknown, such as that due to intrusions or layer pinching. To explore range dependence, investigation and application of high-resolution wavenumber estimation techniques [3] will continue, along with instantaneous wavenumber estimation techniques, based on a reduced interference distribution (RID) implementation of time-frequency representation (TFR)[4] analysis for continuously varying media. The RIDTFR approach yields both modal wavenumber and amplitude information. Using wavenumber information as data, geoacoustic parameter estimates will be sought and compared (for both accuracy and algorithm speed) using linear and non-linear approaches. A hybrid inversion method that combines horizontal wavenumber estimation with non-linear optimization methods, where the wavenumber estimates would be used to determine spatially dependent background models for the non-linear parameter search algorithms is being tested. In addition, to improve the depth resolution of perturbative inversion approaches based on *regularization*, an approach is being pursued which allows for discontinuities in the sediment sound speed profile at interfaces [5]. LFM data collected during SW06 will be analyzed in collaboration with S.D. Rajan and results compared for co-located experiments. Additional areas of research based on analysis of the collected data sets include addressing the impact of watercolumn variability on wavenumber estimation [6], development of an exact inversion algorithm based on discrete reflection coefficient data obtained from wavenumber estimates, and a source depth discrimination tool based on the distribution of energy in horizontal wavenumber spectra.

WORK COMPLETED

The experimental work described for SW06 was completed in August 2006. 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 was retrieved from the VLA/HLA, backed up, and archived for distribution by WHOI. The data were received by the author in December 2006. Algorithms for reducing the raw data to a usable form have been completed. Specific coding has been implemented for demodulating the full time series data into the respective single frequency bands and merging with the spatial track data. Particular care has been to accounting for Doppler shift and spread induced by the moving source to maximize fidelity of the demodulated data. The resulting synthetic aperture data are thus reduced to complex pressure as a function of range from the VLA at each of the transmitted frequencies. Code has also been written to produce spatial representations of the sound velocity field in the water column over each of the acoustic track segments.

RESULTS

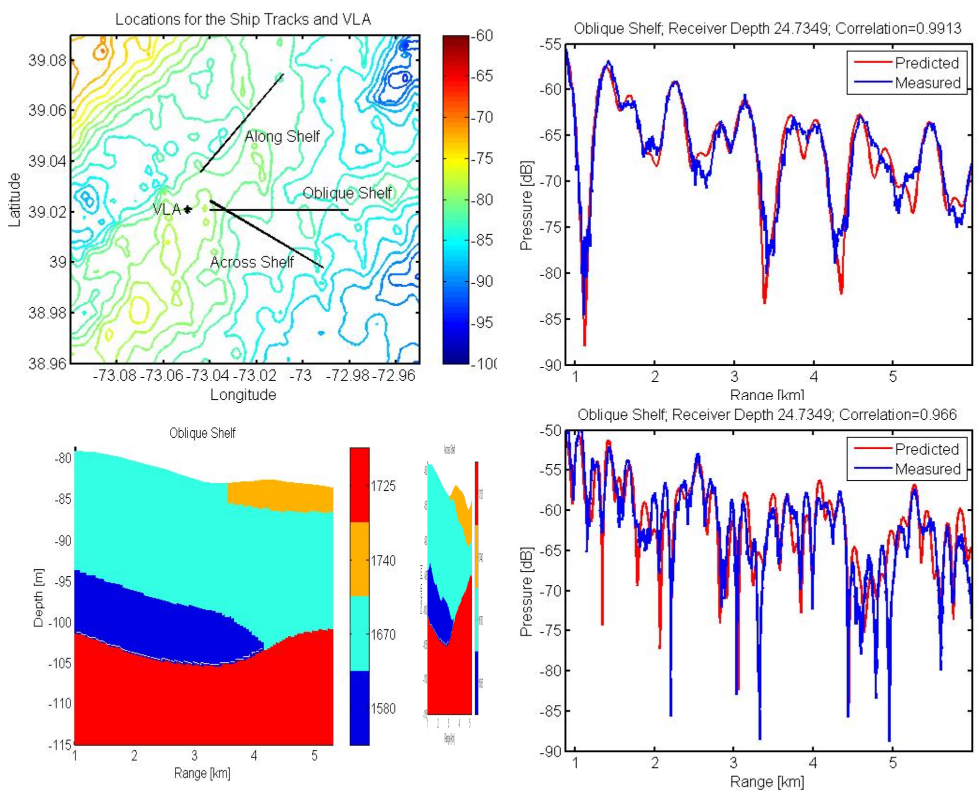

Fig. 2 Geoacoustic inversion was applied to data collected along the East-West (oblique to shelf) track indicated in top-left panel. Sound speed as a function of range and depth resulting from the inversion is shown in the bottom-left. Magnitude of the acoustic pressure field measured at 50 Hz (top-right) and 125 Hz (bottom-right) is plotted with data predicted using the inverted sediment sound speeds. The correlation between measured and modeled data is greater than 95 percent .

Range-dependent values of horizontal wave numbers were determined for four frequencies along the radial tracks indicated in the top-left panel of Fig. 2. Using the wave number estimates at each range as input to a linear inversion algorithm based on qualitative regularization, local estimates of the depth dependent sound speed profile in the sediment were obtained. These results are an improvement to range-independent result reported recently [7] where the low-speed layer was not resolved. A simplified model representing sediment sound speed as a function of depth and range for a track with an East-West orientation, oblique to the shelf slope, is illustrated in the bottom-left panel of Fig. 2. The first three kilometers of the model are represented by two sediment layers over a half-space. The top layer has an average sound speed of 1670 m/s, is ~15 m thick, and runs parallel to the bathymetry. Below this is a layer ~7 m thick with an average sound speed of 1585 m/s that also parallels the bathymetry. The underlying half-space in this region has a sound speed of 1725 m/s. At ranges between 3 and 4 km, the low-speed layer is pinched out by the half-space below and the 1670 m/s layer above. At around 3.5 km in the model, a higher sound speed layer at the surface was found. This layer was a few meters thick and has an average sound speed of 1740 m/s and is consistent with a sand ridge. At ranges greater than 4 km, a two-layer over half-space mode persists, with a 1740 m/s top layer, a 15 – 20 m thick layer with sound speed of 1670 m/s, and 1725 m/s half-space. Using this range-dependent sound speed model, the acoustic field was predicted using a parabolic equation method. The predicted and measured fields are shown for 50 Hz and 125 Hz in the top-right and bottom-left panels, respectively, of Fig. 2. Correlation between measured and predicted fields was greater then 95 percent. Range and depth dependent sediment sound speed profiles were similarly obtained for the ‘Along Shelf’ and ‘Across Shelf’ tracks shown in Fig. 2.

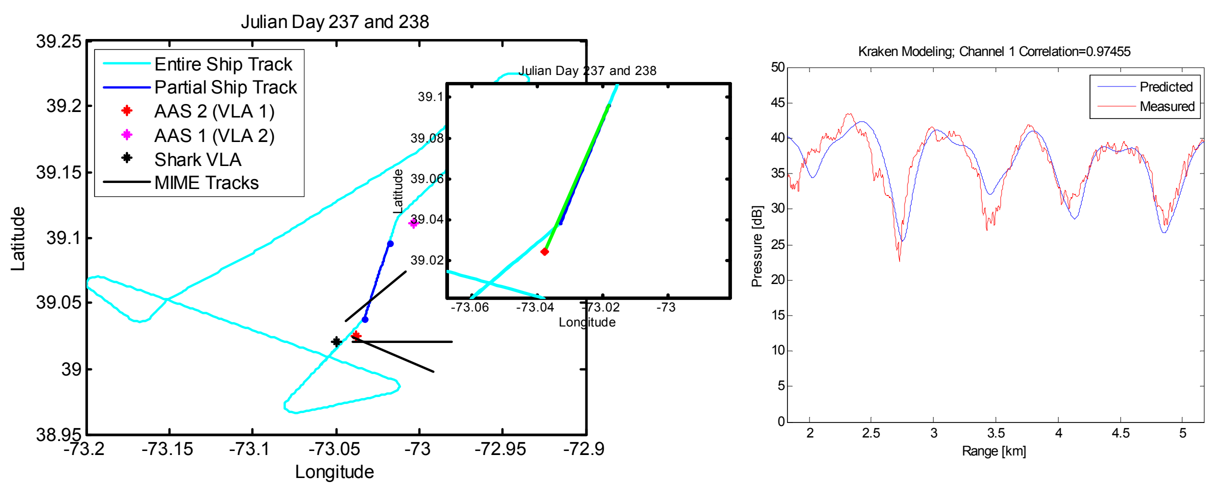

Fig. 3 Comparison of acoustic field predicted using inversion results from MIME with data measured along track indicated in dark blue of left panel. The black lines are the MIME tracks. These data were collected 21 days after data used for inversion and correlation between measured and predicted fields was greater than 90 percent.

Approximately 20 days after the MIME experiment, data were acquired on another VLA for a J-15-1 source towed along a line that crossed the ‘Along Shelf’ track shown in Fig. 2 [8]. It was of interest to predict the acoustic field for this case using the sediment sound speed model obtained for the MIME ‘Along Shelf’ track. The track line and model to data comparison at 53 Hz are shown in Fig. 3 above. For a deep receiver, the correlation between model and data was greater than 95 percent. Correlations greater than 90 percent were also observed for data collected at 103 Hz. However, although not shown here, the data measured on this VLA was much noisier than that recorded on the SHARK VLA during the MIME experiments. It has been reported that the top 4 phones of this VLA were very noisy and un-usable, further, the comparison here is not the data as reported in [8], but another data set taken on the same array. Nevertheless, the excellent agreement between the measured field and the field predicted using the inferred geoacoutic parameters provides validation of the model for this region. This comparison is a first step in validating and synthesizing geoacoustic inversion results from different investigators and methodologies applied to SW06 data.

IMPACT/APPLICATIONS

The application of these results is for geoacoustic inversion in range-dependent shallow water regions. The results are directed to 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 future experimental efforts.

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PUBLICATIONS

M.S. Ballard and K.M. Becker, "Geoacoustic inversion on the New Jersey Margin: Along and across the shelf", J. Acoust. Soc. Am. 123(6), EL141–EL145 (2008) [published, refereed]

K.M. Becker and G.V. Frisk, "The impact of water column variability on horizontal wavenumber estimation and mode based geoacoustic inversion results", *J. Acoust. Soc. Am.*, **123** (2), pp. 658-656 (2008) [published, refereed]

S.D.Rajan, George V.Frisk, Kyle M.Becker, James F. Lynch, Gopu Potty and J. H. Miller, "Modal inverse techniques for inferring geo-acoustic properties in shallow water", in *Important Elements in: Geoacoustic Inversion, Signal Processing, and Reverberation in Underwater Acoustics,* Ed. A. Tolstoy (Research Signposts, ISBN 978-81-308-0248-0 2008) [in press]

HONORS/AWARDS/PRIZES

Graduate Student Megan S. Ballard, working on this project, received best student paper awards at the following conferences:

July 2008 Acoust. Soc. of Am., Paris France - 1st place (lecture) Acoustical Oceanography
M.S. Ballard and K.M. Becker, "Three dimensional geoacoustic inversion on the New Jersey shelf", *J. Acoust. Soc. Am.*, **123**, 3106 (2008)

Nov. 2007, Acoust. Soc. of Am., New Orleans - 2nd place Acoustical Oceanography
M.S. Ballard and K.M. Becker, "Improved perturbative inversion schemes for obtaining bottom geoacoustic properties in shallow water", *J. Acoust. Soc. Am.,* 122 (5), p. 2941 (2007)