Acoustic characterization techniques for shallow water

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LONG TERM GOALS

Variability in the ocean environment can greatly impact acoustic propagation. Sonar systems often show large performance differences depending on location and oceanographic conditions. The long term goals of this research is to better understand the fundamental environmental quantities that impact shallow water acoustic propagation and to develop techniques for both characterizing the environment (for better performance prediction) and for mitigating the impact of environmental variability on sonar performance.

OBJECTIVES

The objectives of this research are to develop methods to better characterize the shallow water acoustic propagation environment. Better knowledge of the environment will improve the capabilities of sonar performance prediction tools and are the basis for improving sonar performance through environmental adaptation of the systems. Many factors can contribute to variability observed in acoustic propagation measurements including wave-height, water-column sound speed properties, bathymetry, and seabed type. Of these factors the seabed type often has the strongest impact on propagation and is one of the quantities (along with bathymetry) that can be measured and archived for future use. The focus of these research objectives is to better characterize the seabed properties through inversion of acoustic measurements.

APPROACH

The approach is to characterize acoustic propagation in shallow water by using acoustic measurements to determine the most important properties of the channel. Some of the data used for these studies involve measurements similar to those available in operational systems. Success with this line of research will provide techniques that allow operational systems to be used for *in situ* environmental characterization and this will ultimately provide inputs for environmentally adaptive processing techniques. Other data used is from research experiments designed to test remote sensing techniques for both estimating the seabed properties and for obtaining a more fundamental understanding of the propagating acoustic field in shallow water channels.

During 2003, four areas of research related to acoustic characterization have been undertaken: 1) geoacoustic inversion using towed arrays, 2) the impact of scattering on matched-field methods, 3) using effective parameters for geoacoustic inversion and 4) geoacoustic inversion at high frequencies (1-16 kHz).

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14. ABSTRACT

Variability in the ocean environment can greatly impact acoustic propagation. Sonar systems often show large performance differences depending on location and oceanographic conditions. The long term goals of this research is to better understand the fundamental environmental quantities that impact shallow water acoustic propagation and to develop techniques for both characterizing the environment (for better performance prediction) and for mitigating the impact of environmental variability on sonar performance.

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WORK COMPLETED

Completed work on towed (horizontal) array geoacoustic inversion shows this is a viable technique that has good potential to be transitioned to navy systems using the appropriate source/array geometry. An analysis comparing vertical and horizontal arrays showed that a towed array can provide reasonable estimates of the seabed properties with sensitivity comparable to that of a vertical array (Ref. 1). In addition to the practical advantages, the towed array geometry also provides for the possibility of mapping range-dependent seabed properties (see Ref. 1 for details). This year, the mapping of range-dependent geo-acoustic properties was demonstrated using measured data and this was presented in Ref. 11 and was submitted for publication (Ref. 13).

The impact of rough boundaries on propagation and matched field methods is also being investigated. A new objective function (used to compare the quality of fit between modeled and measured data) that uses the envelope of the impulse response appears to be less problematic than conventional matched field objective functions. Preliminary results using measured data from the ASCOT-01 experiment demonstrates the value of the new objective function. The new objective function appears more robust than conventional objective functions while retaining sensitivity to some of the most important parameters for inversion. This work was presented in 2003 (Ref. 6,8,10).

The concept of using effective parameters for geoacoustic inversion was successfully demonstrated with test cases from the Inversion Techniques Workshop. For Test Case 1 the bathymetry was sloped and this was solved by matched field inversion using a flat bathymetry and adjusting the position of the source and receivers. The inverted seabed properties showed good agreement with the correct solutions and accurately reproduced transmission loss curves (see Ref. [2] for details).

An initial study using high frequency broadband data for geoacoustic inversion shows promise. The signals used for inversion are those typically used with acoustic modems having a single receiver and signal in the 8-16 kHz band. The envelope of the acoustic receptions showed the details of the multipath structure and when this was measured as a function of source/receiver separation it was a suitable data set to invert for a few key seabed parameters (e.g. critical angle). This work was presented in 2003 (Ref. 9).

RESULTS

1. GEOACOUSTIC INVERSION USING TOWED (HORIZONTAL) ARRAYS

The seabed has a strong effect on acoustic propagation and there are many areas of the world where the seabed properties are unknown. Acoustic measurements can be used in inversion schemes to determine seabed properties but the difficulty is developing simple methods that can produced meaningful seabed properties over areas typical for operational scenarios. While geoacoustic inversion has been successfully demonstrated with at-sea data using vertical arrays, little work has been done for horizontal arrays even though these have a great operational advantage over moored or drifting systems because of the ease in which they can be deployed from a ship. Further, towed systems can operate in a survey mode to map (possibly range-dependent) seabed properties over large areas. The initial demonstration of geoacoustic inversion using a towed array was made from data collected in the MAPEX2000 experiment (conducted in the Mediterranean in 2000).

A careful simulation study was made this year comparing performance of data inversion for seabed properties using vertical and horizontal arrays [1]. In this study, the simulated data was taken from the

ONR/SPAWAR sponsored Inversion Techniques Workshop. The results for the inverted seabed sound speed as a function of depth for both vertical (VLA) and horizontal arrays (HLA) is shown in Fig. 1. The figure shows that both the VLA and HLA capture the main features of the seabed. In this case the VLA contained 60 hydrophones and was 80 m in length spanning most of the water column. The HLA was 300 m in length containing 60 hydrophones.

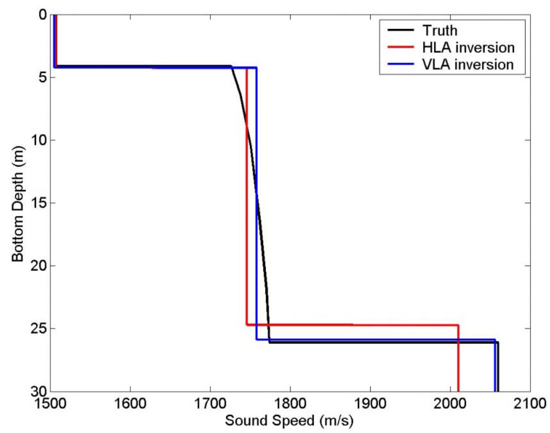

Figure 1: Seabed layering and sound speed: ground-truth (black line), inverted HLA data (red line) and inverted VLA data (blue line) (inversions are for Inversion Techniques Workshop Test Case 1). The geoacoustic model used in the inversions was 2-layers over a sub-bottom (ground truth has many layers).

For Test Case 1, the geoacoustic properties were range independent and there was little difference between using a HLA or a VLA. However, for Test Case 3, the bathymetry was flat but there was a hidden intrusion in the seabed. In this case, the towed horizontal array was ideal for determining the range-dependent seabed properties. The vertical array configurations were problematic because the propagation path was over different seabed types resulting in inversions for spatially averaged properties. Using a simulated towed, horizontal array, the range dependent seabed properties were well determined along the entire track and in this case, the towed horizontal array inversion method out-performed the vertical array inversions (Ref. 1).

This research has also been in collaboration with a new project that started in 2003 at the Naval Research Laboratory (T.C. Yang) and with the NATO Undersea Research Centre. A variety of issues and approaches have been addressed in this collaborative work including sensitivity to array element location (Ref. 12) and mapping range-dependent geoacoustic properties with a towed array (Ref. 11, 13).

2. ANALYSIS OF THE IMPACT OF HIGHLY REFLECTIVE, ROUGH BOUNDARIES ON INVERSION TECHNIQUES

Controlled acoustic measurements were made during the ASCOT-01 experiments and these have been used to determine the impact of a highly reflective, rough seabed on inversion methods in the 200-2000 Hz frequency band. The reflective seabed produces a long duration of multipath arrivals. Intuitively this should provide clues for inversion algorithms as to the seabed type, however, using well established techniques of matched field inversion this data proved to be extremely challenging to invert. The likely cause of the difficulty appears to be the high degree of scattering from energetic late arrivals. Fig. 2 shows measured and simulated arrival patterns.

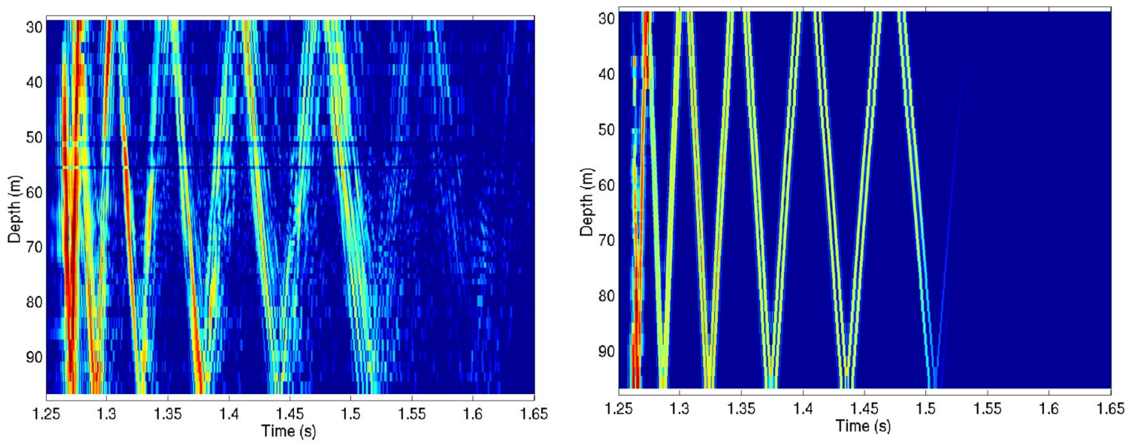

Figure 2: Left panel shows a 200-800 Hz impulse response measurement taken on a vertical hydrophone array at 2-km from the source (ASCOT-01). Right panel shows a simulation of the same geometry. The broken pattern observed in the late arrivals in the measured data is likely caused by scattering which is not included in the modeled results shown at the right.

3. EFFECTIVE PARAMETERS FOR INVERSION

One of the hurdles in developing model based geoacoustic inversion algorithms occurs when measurements are made in areas with range-dependent bathymetry. This typically presents difficulties for two reasons, first, the exact bathymetry as well as source/receiver geometry must be known to less than wavelength precision and second, numerical modeling must include range-dependence and this often slows the calculations making inversion algorithms impractical or impossible. Alternatively, these unknown geometric parameters can be included in the inversion search, but this introduces a potentially much larger set of parameters to match.

Using a simple time-domain view it can be shown that it is sufficient to use a range-independent model with an empirical “effective” water depth even when the bottom is not flat. Along with an effective water depth, the source and receivers have corresponding effective ranges and depths. In fact there is a set of effective environments and source/receiver geometries that will suffice and we can choose whichever is the most convenient (often a flat, range-independent bathymetry). Examples of effective parameterization are shown in Fig. 3. In both cases, the range-dependent bathymetry is replaced by a range-independent one- different choices for the flat bottom water depth will determine the exact source and receiver locations (see Ref. [3] for details).

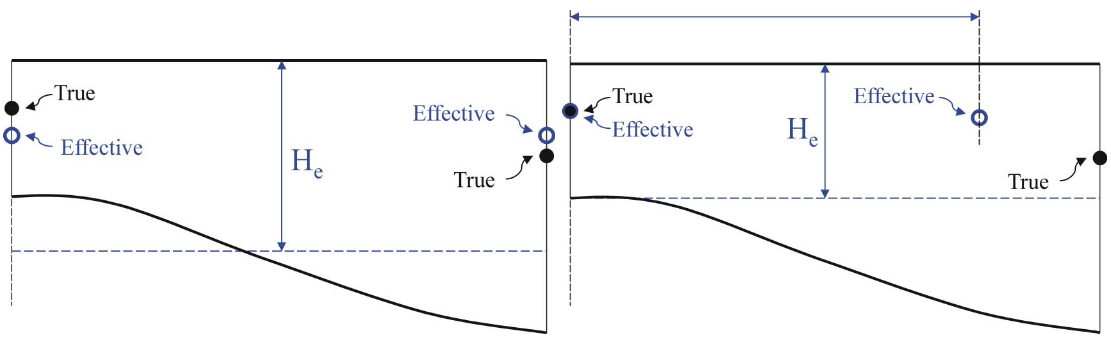

Figure 3: Left panel shows the shift in source receiver positions when the range-dependent bathymetry is replaced by a flat, average depth. In the right panel the flat bottom water depth is chosen equal to that at the source and therefore the true and effective source positions are the same while the receiver position is shifted.

4. GEOACOUSTIC INVERSION AT HIGH FREQUENCIES

This year, preliminary work has begun on determining geoacoustic properties using acoustic data in the frequency band 1-16 kHz. Many applications, including acoustic communications, operate in this band and identifying the seabed properties is extremely important for predicting performance. Initial work matching broadband acoustic time series envelopes with modeled data shows that some of the more sensitive parameters can be estimated. The signals used in the inversion were taken from acoustic modems (single source and single receiver) in the 8-16 kHz band. The results presented this year showed a consistency with measured grain size analyses for the site considered in the study (Ref. 9).

IMPACT/APPLICATIONS

This work will improve at-sea situational awareness and will also improve the ability for systems to predict where and to what range underwater targets will be detected. With improved environmental characterization there is also potential to optimize sonar parameters (e.g. towed array depth, signal type and source levels) for better performance. This research has not yet been transitioned to operational systems. However, the effort on inversion using towed arrays is being used with measurements from the NATO towed array active sonar and there is currently an effort to develop the techniques for *in situ* environmental adaptation for that system.

RELATED PROJECTS

There is a related project at the Naval Research Laboratory under the supervision of T.C. Yang. There is also a similar line of research at the NATO Undersea Research Centre being conducted by Peter Nielsen and Mark Fallat. Much of the work described here for 2003 has been in close collaboration with these research laboratories. This collaboration is expected to continue in the future. Some of this research has been done with the support of and in connection with the ONR sponsored project, Effects of Sound on the Marine Environment (ESME). Work on HF inversion is linked to OA321 “High-Frequency Channel Characterization Experiment (HFX)” and OM321 “SignalEx” on acoustic communications in the HF band.

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