

The impact of range-dependent sediment properties on the acoustic field in 2-D shallow water environments

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LONG-TERM GOALS

The goal of this research is to understand the effects of range-dependent sediment properties on the acoustic field in 2-D shallow water environments. This information, in part, is required to solve the statistical inference problem in inhomogeneous shallow water environments.

OBJECTIVES

The spatio-temporal variability of the water column needs to be properly accounted for while looking for the effect of range-dependent sediment properties on the acoustic field. The objective of the current work is to create a high-fidelity model of the water column along a single propagation track for the Shallow Water 2006 (SW06) experiment. The water column model will include the propagation of nonlinear internal waves through the environment. The purpose of the water column model is to reduce the mismatch between measured and modeled acoustic data so that range-dependent sediment properties can be investigated.

APPROACH

The main goal of the work is to investigate the impact of range-dependent sediment properties on the acoustic field in the SW06 environment. However, during an analysis of acoustic data in the region of interest, it was observed that the passage of internal waves caused significant temporal fluctuations in the acoustic data. This observation is common to many shallow water regions of the ocean.^{1,2,3,4,5,6} When looking for range-dependent sediments using acoustic data, it may be important to separate the part of the acoustic field that depends on spatio-temporal fluctuations of the water column from the part of the acoustic field that depends on range-dependent sediment properties.

It is hypothesized that internal waves might be used to enhance sensitivity to seabed properties. Enhanced sensitivity might occur when internal waves scatter low-angle acoustic modes into high-angle modes, thereby increasing the interaction of the acoustic wave with the seabed as it propagates. The technical challenge of this problem is to deterministically model the water column with enough fidelity

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so that mismatch between measured and modeled acoustic data, caused by errors in the water column model, does not overwhelm one’s ability to infer range-dependent seabed properties.

The approach taken here was to develop a data-driven water column model of the SW06 region and link it to an acoustic propagation model. The acoustic predictions from the model are then compared with measured acoustic data from the SW06 experiment to determine the usefulness of the water column model and the extent to which it can be used to predict fluctuations in received acoustic intensity. The water column model encompasses a 30 km track between SW47 and SW54 as shown in Fig. 1. Data from four oceanographic moorings (SW47, SW29, SW03, and SW54) were used to construct a slowly-varying background water column sound speed profile $\bar{c}(r,z,t)$ (with internal waves removed) and to estimate internal wave properties that would later be used to add sound speed perturbations $\delta c(r,z,t)$ to the background field. In this environment, the wavefronts of the internal waves were generally perpendicular to the line connecting SW47 and SW54, making mode coupling the dominant acoustic propagation regime.⁷

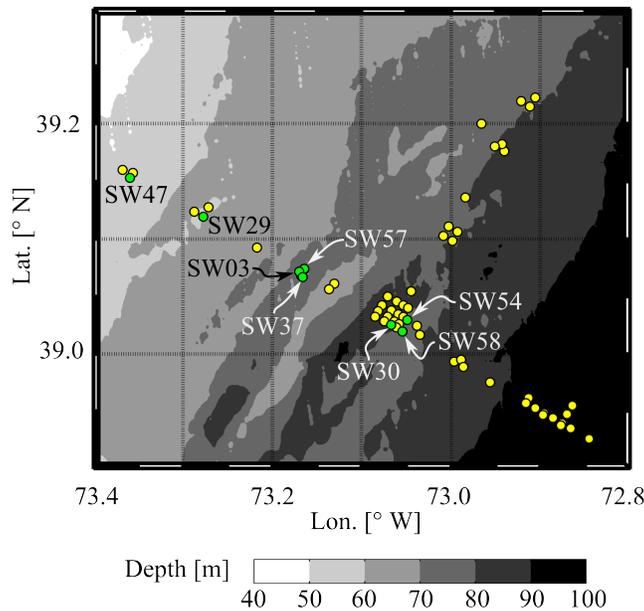


Figure 1: Map of the SW06 experimental region. Water depth is shown in gray scale. Mooring locations are shown by dots. The focus of this work is a region defined by the line connecting SW47 and SW54.

An acoustic source was moored at SW47 and acoustic intensity was received on a vertical hydrophone array at SW54. The received acoustic intensity as a function of time was integrated over depth to create depth-integrated intensity. Because depth-integrated intensity captures the vertical distribution of energy in the water column, fluctuations in this quantity reflect changes in the net attenuation experienced by the acoustic wave as it is scattered by the internal wave field. Depth-integrated intensity was chosen as the acoustic metric for the comparison between measured and modeled data. The usefulness of the water column model will be assessed by using it to predict the acoustic depth-integrated intensity received on SW54.

WORK COMPLETED

The work completed includes the following items:

1. Creating $\bar{c}(r, z, t)$ from measured oceanographic data.
2. Creating a database of soliton properties for specific internal wave events from measured oceanographic data.
3. Creating a water column model to incorporate both $\bar{c}(r, z, t)$ and $\delta c(r, z, t)$.
4. Linking the water column model to the Range Acoustic Model (RAM) to compute depth-integrated acoustic intensity at the SW54 VLA.
5. Processing acoustic data at the SW54 VLA over 21 days of the experiment.
6. Comparing the modeled acoustic data to the measured acoustic data to validate the water column model.

RESULTS

The results presented in this section are enumerated to match the outline given in the previous section. Items 4, 5, and 6 are combined into a single discussion in this section.

1. Background sound speed profile, $\bar{c}(r, z, t)$

The range, depth, and time dependent background water column sound speed profile is shown in Fig. 2. This reconstruction was derived from measured temperature and salinity data recorded on the SW47, SW29, SW03, and SW54 moorings. The data were filtered to include temporal fluctuations with periods less than one cycle per day. Significant range and time dependence are visible in the figure. Notable range-dependent features include the “cold pool” which exists on the shelf and the warm water intrusion which exists near the bottom of the water column at moorings SW03 and SW54. The time dependence of $\bar{c}(r, z, t)$ is also clearly visible in Fig. 2.

2. Soliton properties

Range- and time-dependent soliton properties were estimated from the mooring data after a filter was applied to include data fluctuations with periods greater than 10 cycles per day. The depth of the 16° C isotherm was used to estimate the number of solitons in each packet and to estimate the heights, widths, and spacings of the solitons as they propagated up the shelf from SW54 to SW47. Soliton properties were computed at each of the four mooring locations for approximately 20 different soliton packets during the experiment. The database of soliton properties will later be used in conjunction with $\bar{c}(r, z, t)$ to create reconstructions of the water column. For illustrative purposes, the modeled depth of the 16° C isotherm at each mooring, compared to the measured isotherm depth, for soliton packet “Rosey” is shown in Fig. 3. The 16° C isotherm was chosen because it was consistently located near the middle of the thermocline.

3. Water column model

The water column model consists of a slowly-varying background sound speed profile $\bar{c}(r, z, t)$ with soliton perturbations $\delta c(r, z, t)$ added to simulate the rapidly-varying internal wave field. The temporal/range dependence of the soliton packet was computed from the properties stored in the soliton

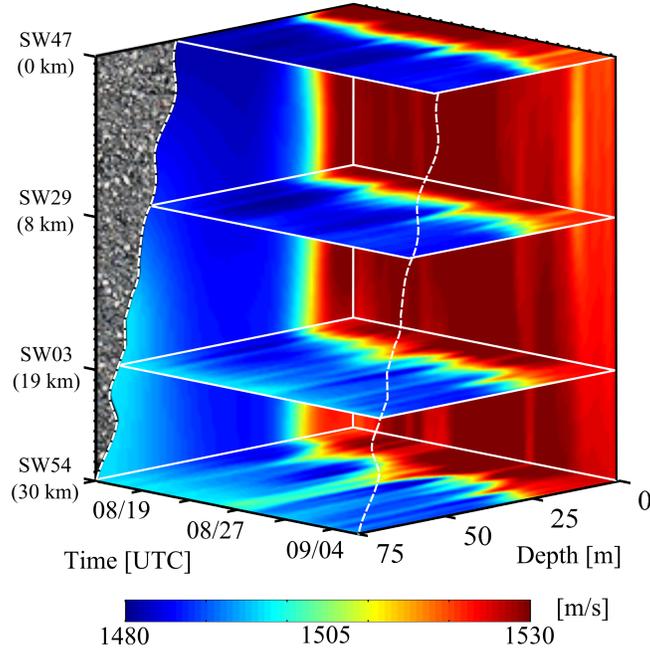


Figure 2: Graphical slices of $\bar{c}(r, z, t)$ at SW47, SW29, SW03, and SW54. Sound speed is depicted by the color scale. The variable bathymetry is shown by the dotted line.

database and the vertical structure was defined by the first internal wave mode, computed using temperature and salinity data from the oceanographic moorings. An example of the modeled water column sound speed profile for one instant in time during internal wave packet “Rosey” is shown in Fig. 4.

4-6. Comparison between measured and modeled acoustic data

The water column model was linked to the acoustic propagation code RAM, so that the acoustic field could be computed at specific times. The range, depth, and time dependent sound speed profile, along with assumed geoacoustic properties, served as the inputs to RAM. Depth-integrated intensity was computed from the model and compared to depth-integrated intensity from experimental data. The comparison is shown in Fig. 5. Note that not all of the soliton events during the SW06 experiment have been modeled in this figure.

The qualitative agreement in the depth-integrated acoustic data appears to be good. The deterministic model of the water column sound speed profile is capable of capturing and predicting the physics involved with the acoustic propagation (namely, the modal scattering from low-angle acoustic modes into higher-angle acoustic modes). To our knowledge, this level of agreement between measured and modeled acoustic data, using a deterministic model to describe internal waves, has not been accomplished to date.

However, one challenge of the deterministic water column model has become apparent. Although the agreement is quite good on the time-scale shown in Fig. 5, the agreement is not as good on shorter time scales if one looks at intensity as a function of depth. As an example, the acoustic intensity received on each hydrophone in the VLA is shown in Fig. 6. There is generally good qualitative agreement between the measured and modeled acoustic intensity, but there are regions in the figure where the error exceeds 20 dB. This might represent a practical limitation on the ability to deterministically model the water

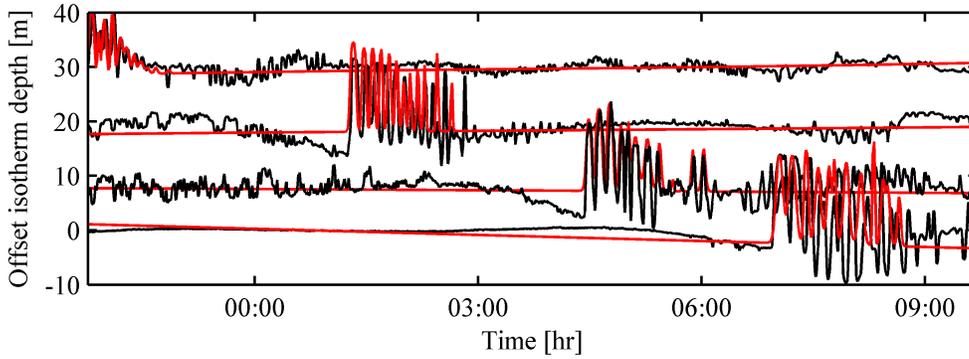


Figure 3: Depth of the 16° C isotherm at SW47, SW29, SW03, and SW54 for measured data (black) and water column model (red). The units of the vertical axis are m, but the moorings are offset by their distance in km from SW47 [1 km = 1 m].

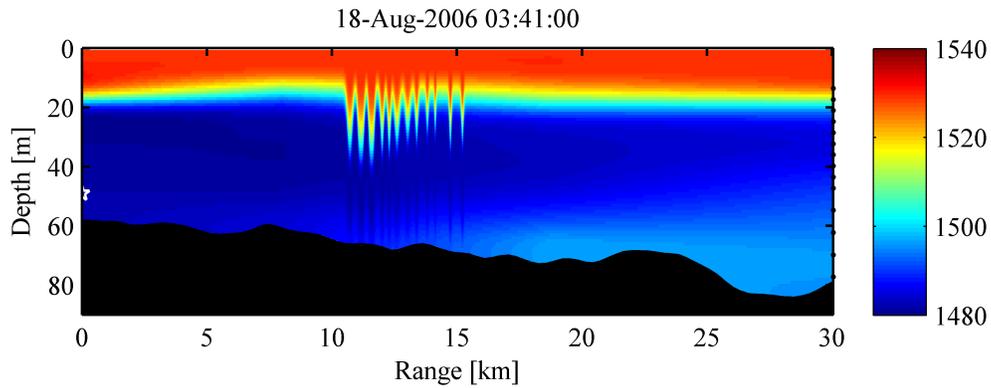


Figure 4: Modeled water column sound speed profile during internal wave packet “Rosey” on 18 August 03:41 [UTC].

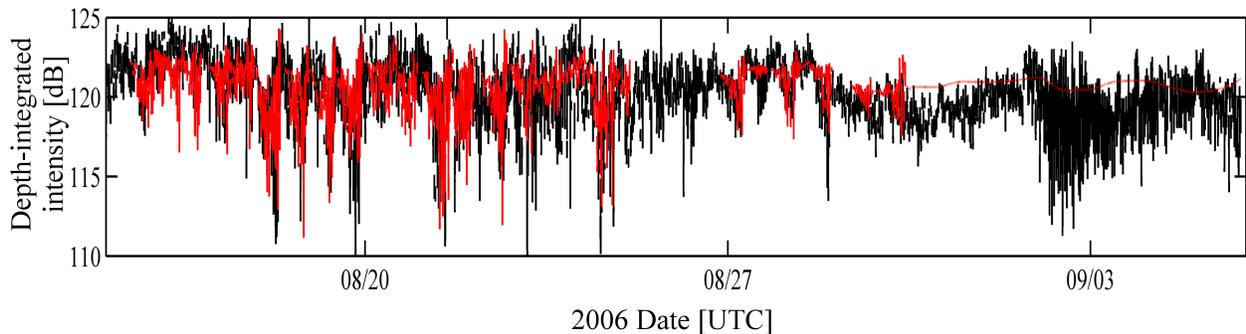


Figure 5: Measured (black) and modeled (red) depth-integrated acoustic intensity received at the SW54 VLA.

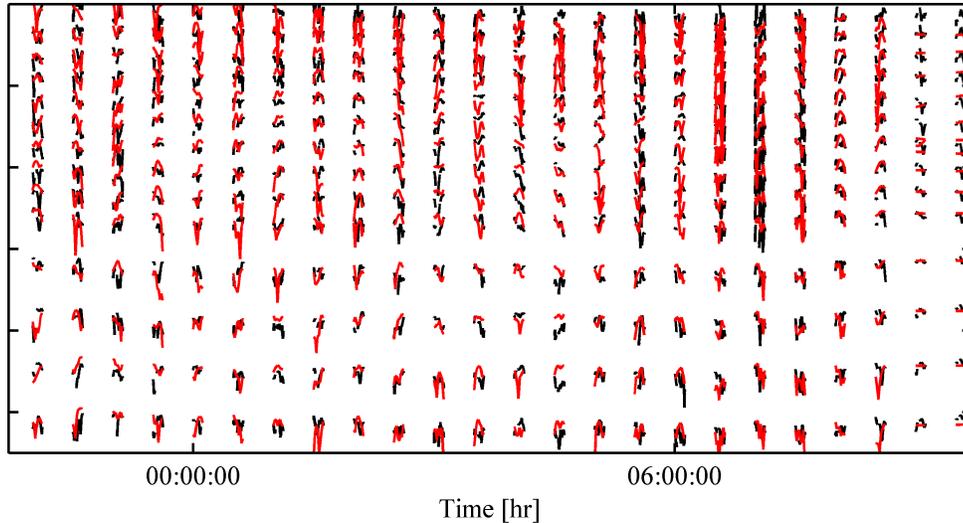


Figure 6: Measured (black) and modeled (red) acoustic intensity received at the SW54 VLA. The data for each hydrophone are offset according to hydrophone depth. The distance between vertical tick marks is 50 dB.

column in such a way that explains short-time fluctuations in received acoustic intensity.

IMPACT/APPLICATIONS

The impact of this research is to increase the understanding of physical propagation mechanisms in shallow water environments and to identify important modeling considerations that must be accounted for to decrease uncertainty in model prediction. The research can be applied to propagation models of all types and can also be used in geoacoustic inversion and inference problems.

TRANSITIONS

The primary transition for this project is a high-fidelity water column model to be used in concert with an acoustic propagation model for the SW06 environment.

RELATED PROJECTS

None.

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