Mid-Frequency Sound Propagation, Reverberation, and Geoacoustic Inversion in Shallow Water

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LONG-TERM GOALS

The long-term goals of this work are (1) to use propagation or reverberation data to extract sediment geoacoustic parameters that can then be used to predict long range reverberation in shallow water; and (2) to validate such remote sensing techniques for geoacoustic inversion and their uncertainties using localized sediment ground truth measurements.

OBJECTIVES

The objectives of this effort are

(1) to use localized sediment ground truth measurements to validate inversion results sufficiently to provide geoacoustic information to quantitatively predict long range propagation;

(2) to improve understanding of mid-frequency sound propagation under the internal tides and nonlinear internal waves (NLIW);

(3) to develop a reverberation model due to boundary roughness using a Monte Carlo approach.

APPROACH

During SW06 extensive acoustic and environmental data were taken for various purposes. The acoustic/ ocean data sets and models, which are directly related to the objectives of this effort, are listed as follows.

1. Direct measurement of sediment sound speed using SAMS

SAMS is an instrument to measure *in situ* sediment sound speed through acoustic time delay measurements. SAMS was built with a DURIP Grant (N00014-05-1-0425) and the analysis of data collected in SW06 was in collaboration with Dajun Tang (APL-UW). In SW06, the maximum depth of measurement was 1.7 m, with a depth stepsize of approximately 0.1 m. A total of three deployments were made with the first two about 500 m apart. These two deployments are close to the center of the

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14. ABSTRACT
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SW06 experimental site where acoustic and physical oceanography (PO) data were taken. The sediment sound speed from the direct measurement provided a basis for assessing geoacoustic inversion results obtained nearby.

2. Mid-frequency propagation: ocean and acoustic data

Two of the mid-frequency propagation data sets collected during SW06 were made on Aug. 18 and 19. One is an 8 km towed source run; the other is at a fixed 550 m range before, during, and after the passage of nonlinear internal waves (NLIW). The two data sets combined with supporting environmental data using the moorings were used to study the acoustical effect of slow time-varying internal tides.

Another mid-frequency propagation data taken on Aug. 13 at a fixed range of 1 km. Simultaneous measurement of sound speed field as a function of depth and range was conducted using a towed CTD chain (Frank S. Henyey, APL-UW). The sound speed field was projected onto the acoustic path for modeling mid-frequency propagation through the nonlinear internal waves.

Both data sets were collected near the two SAMS deployments as well as a cluster of PO moorings (thermistor chains, CTDs, IW tracking, P/S/T/ADCP moorings, etc.) to provide supporting environmental data for modeling purposes. The analyses of both data sets and modeling are in collaboration with Dajun Tang, Frank S. Henyey, and Daniel Rouseff (APL-UW).

3. Models used

Both PE and normal mode propagation models are used for modeling purpose. In addition, a normal mode code developed by Henyey et al. at APL-UW [1] was used for modeling reverberation due to bottom roughness (Yang et al., 2008). The APL normal mode code not only includes the trapped modes but also the leaky and continuum modes for short time behavior.

WORK COMPLETED

1. Analyses of SAMS sediment sound speed direct measurement data taken in SW06 and comparison with other direct measurement techniques and inversion methods.
2. Data/model comparison of mid-frequency sound propagation in shallow water under the influence of slow time-varying internal tides.
3. Mid-frequency sound propagation through the episodic nonlinear internal waves.
4. Development of a normal mode based reverberation model to study reverberation due to bottom roughness using first-order perturbation theory and Monte Carlo approach.

RESULTS

Direct measurement of sediment sound speed and comparison/validation with other direct measurement techniques and inversion methods.

During the Shallow Water ’06 experiment, in situ sediment sound speed was measured using the Sediment Acoustic-speed Measurement System (SAMS) in the frequency range 2–35 kHz. Analysis of localized ground truth measurements using SAMS in SW06 has been published in JASA-EL (see Publication). Results from three deployments show that SAMS was capable of determining sediment sound speed with uncertainties less than 1.6% and the results have been used by other PIs as a reference value for their inversion effort. The comparison of SAMS sediment sound speed with another direct measurement technique, the geo probe, and various inversion techniques shows good agreement (see Fig. 1).

Acoustical effects of the slow time-varying internal tides

Nonlinear internal waves on the continental shelf depress the thermocline and thicken the surface mixed layer with consequent effect on acoustic propagation. After the waves have passed, it may take several hours for the thermocline to rise to its pre-wave level. The slow rising thermocline caused by the internal tide trailing the waves is relevant to acoustics because it may last for several hours while nonlinear internal waves may transect a given acoustic track for only a small fraction of the tidal period. To examine the effect of the rising thermocline, oceanographic and acoustic data collected during the Shallow Water 2006 Experiment are analyzed. Mid-frequency acoustic data taken for several hours at both fixed range (550 m) and along a tow track (0.1—8.1 km) are studied. At the fixed range, the rising thermocline is shown to change acoustic intensity by 5 dB. Along the tow track, the transmission loss changes 2 dB for a source-receiver pair that straddles the thermocline. The effects on acoustic signals are shown to be observable, significant, and predictable. The above results are reported in a paper to IEEE JOE (accepted, see Publication).

Non-stochastic study of mid-frequency sound propagation through the episodic nonlinear internal waves.

During the Shallow Water 2006 experiment, a towed CTD chain was used to measure internal waves and provide sound speed field as a function of range and depth. The measurements were coordinated so that the nonlinear waves can be projected onto the acoustic path for deterministic predictions of acoustic propagation. Simultaneous acoustic measurements were made in the frequency band of 1.5 to 10.5 kHz over a 1 km path. Using the measured sound speed field, the acoustic arrival patterns under the influence of the nonlinear internal waves are modeled and shown good agreement when compared with data. It has been shown that the NLIW’s have a significant effect on the travel time, even though the waves during this experiment were rather small in amplitude.

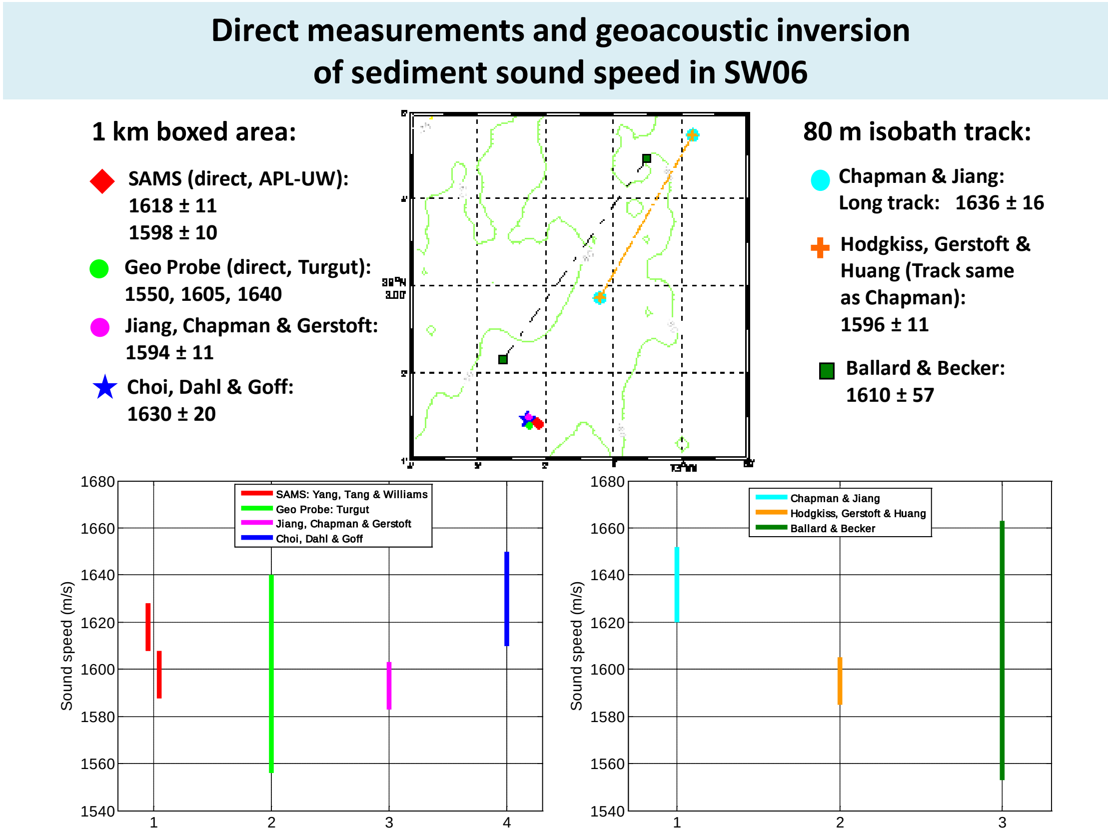

Figure 1 Comparison of sediment sound speed between direct measurements and geoacoustic inversion in SW06.

Development of a normal mode based reverberation model due to bottom roughness using a Monte Carlo approach.

Reverberation in a 2-dimensional Pekeris waveguide with a rough bottom is considered. The field is calculated based on first-order perturbation theory using normal modes. The field is calculated at individual frequencies and then Fourier synthesized into the time domain. Realizations of bottom roughness distribution are generated and corresponding reverberant fields are calculated to obtain the average reverberation intensity. A normal mode code developed by APL-UW [1] is used to include not only the trapped but also leaky and continuum modes to improve model accuracy in the near field. The normal mode reverberation model results are compared well with PE and ray based models using one problem setup by the Reverberation Modeling Workshop [2]. It is also found that the contribution from the "untrapped" modes may be negligible after 0.65 seconds, and therefore the model accuracy is sufficient when including only the trapped modes after 0.65 seconds.

IMPACT/APPLICATIONS

Direct measurement of sediment geoacoustic properties

The potential of using SAMS to access the spatial variability of sediment properties and to obtain reliable statistics was certainly demonstrated. It will not only help better understand bottom property statistics but also provide validation for geoacoustic inversion models.

Mid-frequency sound propagation

Studies of sound propagation in shallow water in the frequency range of 2-10 kHz are very limited. The work completed here on mid-frequency sound propagation through both the linear and nonlinear internal waves can be valuable to the others in the community. Using simultaneous ocean data, deterministic understanding of mid-frequency propagation has been achieved. The understanding of the propagation effects through a dynamic environment, i.e. an environment with the internal waves, has impact on studies such as geoacoustic inversion.

Reverberation modeling

The current model can be extended to study reverberation in a more complex shallow water environment like SW06 and use gained knowledge (through numerical experiments) as guidance for future experiments, to study the sensitivity of environmental parameters to reverberation and bottom statistics.

RELATED PROJECTS

The reverberation modeling work has been conducted in collaboration with Dajun Tang and Eric I. Thorsos at APL-UW for the Reverberation Modeling Workshop funded by ONR.
http://ftp.ccs.nrl.navy.mil/pub/ram/RevModWkshp_II

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[1] F. Henyey and S. Reynolds, personal communication.

[2] http://ftp.ccs.nrl.navy.mil/pub/ram/RevModWkshp_II/Workshop_I_Problem_Definitions

PUBLICATIONS

Frank S. Henyey, Kevin L. Williams, Jie Yang, and Dajun Tang, "Simultaneous nearby measurements of acoustic propagation and high-resolution sound speed structure containing internal waves", (submitted).

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