Shallow Water Mid-Frequency Research and FY07 Experiment

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LONG-TERM GOALS:

To understand mid-frequency (1-10 kHz) acoustics in shallow waters through measurements and modeling, including propagation, reflection, and forward- and backscatter. The top-level goals of this effort are to understand the important environmental processes, which impact mid-frequency sonar performances in shallow water environments; and to develop means to efficiently collect those environmental data.

OBJECTIVES:

The LEAR acoustics field experiment as part of Shallow Water 2006 (SW06) project yielded abundant data sets carefully collected for the purpose of investigating mid-frequency (1-10 kHz) acoustics interacting with environments. Both acoustic data and relevant environmental data were measured contemporaneously to facilitate close model/data comparison.

Acoustics objectives and tasks:

1. Direct-path bottom backscatter – what are the most important physical mechanisms? Equipment: APL 32 element vertical line array and DRDC, Canada parametric system.
2. Single interface forward scatter – what are the most important physical mechanisms (with by Peter Dahl). Equipment: APL's MORAY/BASS.
3. Short range (500 – 1000 m) propagation through internal waves – can acoustic interaction with internal waves be modeled using deterministic measurements of internal waves? ? Equipment: APL's MORAY/BASS. In collaborations with oceanographic measurements by Henyey and Moum.
4. Long-range (10 km) propagation – can multiple interactions with rough boundaries actually simplify the field present at long ranges? Equipment: APL's MORAY/BASS. Complementary data from Scripps, University of Victoria, and DRDC, Canada.

Environmental measurements:
Environmental measurements include in situ and remote sensing components. It is important to cover all relevant environments with adequate sampling. The environments include the sea surface (Buoys, Graber and Dahl), the water column (Internal waves by Henyey and Moum, as well as moorings from WHOI), and the sea bottom (APL IMP/Laser, SAMS and NRL Chirp sonar and Geo-probes, both deployed by Turgut).

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APPROACH

We successfully completed the comprehensive LEAR (Littoral Environmental Acoustics Research) field measurement off the New Jersey coast in the summer of 2006. Starting with assumptions and hypotheses based on current knowledge of the field, we combined acoustics measurements with modeling efforts using the measured environmental parameters to achieve quantitative model/data comparisons of sound fields interacting with bottom, surface and the water column. We started from a local area on the order of 100 m by 100 m, and studied single interactions of sound with the bottom and the surface over space and time. We investigated multiple (2 – 3 bounces) interactions of sound field with the bottom and surface. The point here is to combine the modeling results dealing with individual interaction into an integrated model. Finally, we started modeling the long- range propagation measurements over a range of 10 km. By necessity, the experiment consisted of an acoustics part and an environmental measurement part. We emphasized carrying out environmental measurements at sufficient resolution to properly answer the acoustic questions to be addressed. The acoustics topics included:

1. Single boundary interaction backscattering – what are the most important physical mechanisms?
2. Single boundary interaction forward reflection and forward scattering – what are the most important physical mechanisms?
3. Multiple boundary interactions – Can we successfully combine our knowledge of single interactions to predict the results of a small number of surface and bottom interactions?
4. Long-range (10–20 km) propagation and reverberation – can multiple interactions with boundaries actually simplify the field present at long ranges?

Environmental measurement topics included in situ and remote sensing components. They are:

1. In-sediment measurements of sound speed in the bottom over a depth of 1.7 m with spatial resolution of 5-10 cm in depth (Equipment: APL SAMS).
2. In situ measurements of bottom roughness and volume heterogeneity over several meters with horizontal spatial resolution of 1 cm and vertical resolution of 1 mm (IMP2 with laser scanner).
3. In situ measurements of sea surface roughness spectra and wind speed (Graber, Dahl).
4. Measurement of nonlinear littoral internal waves using a CTD chain vs. time and space (Henyey) and using a multi-purpose probe (Moum).
5. Remote sensing using chirp sonar to estimate sediment geo-acoustic properties over large areas. (Turgut).

In addition, we investigated how to estimate key environmental parameters using only acoustic fields from reflection and backscatter. This will be accomplished by optimizing forward model parameters with acoustic data. For this to be successful, ground truth data (SAMS) in at least one spot is critically necessary.

WORK COMPLETED

We concentrated in the past year on data analysis and modeling. Highlights are:

1. Analysis of SAMS in situ measurements of sound speed in three locations within the SW06 area.
2. Analysis of sound scattering by internal solitary waves.
3. Model/data comparison of long range propagation of mid-frequency sound in shallow water
4. Analysis of seafloor roughness from conductivity and laser scan measurements to support bottom backscatter modeling.

RESULTS

1. The SAMS analysis shows that the top 1.7 m sediments are homogeneous with a mean sound speed of 1610 m/s. This result will be important to the SW06 community to support various inversion schemes. Two papers on this subject are being prepared for the JASA-EL special issue. A new ONR post-doctorate scholar, Jie Yang, has been heavily involved in the data analysis.

2. The work on mid-frequency sound interaction with internal waves has been done through two collaborations, one with Henyey, the other with Moum. This part of research is unique in that we measured deterministic features of the internal waves in the acoustic path. This kind of measurements makes it possible to make non-stochastic model/data comparison. Observed are effects of splitting of arrivals due to the presence of solitary waves and due to the change of thermocline depth before and after the internal waves. Two papers on this subject are being prepared for the JASA-EL special issue.

3. Long range propagation measurements were made by several institutions during SW06 along the same acoustic path. We concentrated on mid-frequency sound propagation in the range of 1 km to 10 km. It is found that the sound waves in the shallow water environment behave like deep water waves when the range exceeds 4 km due to the trapping of waves in the sound channel between the surface thermocline and a warm bottom layer from a front. One paper on this subject is being prepared for the JASA-EL special issue.

4. A new laser scanner were developed, in collaboration with Wang of Taiwan, and deployed along with IMP2, and APL sediment conductivity system, to measure bottom roughness. Two major accomplishments were achieved in this effort. The first is that the laser scanner was able to measure bottom roughness to mm scales, making it possible to support modeling bottom backscatter to much higher frequencies than before. The overlapping regions of the laser scanner and IMP2 yielded consistent result. The second is that we were able to estimate shell distributions on the seafloor – paving the way to quantitatively assess scattering by shell fragments.

IMPACT/APPLICATIONS

While the LEAR experiment addresses many basic science questions, our goal is to improve mid-frequency sonar performance in shallow waters environments. We anticipate impacts in three areas:

First, because we measured all relevant environmental parameters influencing sound waves, we will be able to identify the important environmental process, hence providing the applied community what environmental process to focus on. Second, the direct measurement of sound speed in sediment using SAMS provided a basis for validating bottom inversion schemes. Third, the study on sound interaction with internal waves could provide insight in reverberation clutter. Finally, the laser scanner results provide unprecedented details of bottom scatterers which are sources of backscatter and reverberation.

RELATED PROJECTS

NonLinear Internal Wave Initiative (NLIWI). http://www.nliwi.org

PUBLICATIONS

The following manuscripts are under preparation to be submitted to the Journal of Acoustical Society of America Electronic Letters in a special issue dedicated to the SW06 experimental results.

Simultaneous nearby measurements of acoustic propagation and high-resolution sound speed structure containing internal waves, Frank Henyey, Kevin Williams, DJ Tang

Mid-frequency sound propagation through internal waves at short range with synoptic oceanographic observations, Daniel Rouseff, DJ Tang, Kevin Williams, James Moum, Frank Henyey, and Zhongkang Wang

A sediment acoustics measurement system (SAMS) to acquire in situ sound speed, DJ Tang, Kevin Williams, Russ Light, Vern Miller, and Jie Yang

Direct Measurements of Sediment Sound Speed Using SAMS in SW06, Jie Yang, DJ Tang, and Kevin Williams

Interpretation of a moving source noise recorded near the ocean bottom, DJ Tang, Frank S. Henyey, and Arthur Newhall

Mid-Frequency Long range propagation in Shallow Water, DJ Tang, Kevin Williams, and Dan Rouseff, Peter Dahl, Jee Woong Choi, Zhongkang Wang and Jorge Quijano

Seafloor Roughness Measurement by Laser Line Scanning and Conductivity Probe at SW06 Experiment Site, Chau-chang Wang and DJ Tang

Estimating shell fragment distribution on the seafloor from images of laser scans, Chau-chang Wang and DJ Tang

Range evolution of vertical spatial coherence, Peter Dahl and DJ Tang,