

Shallow Water Mid-frequency Research and SW06

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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 that impact mid-frequency sonar performances in shallow water environments, and to develop means to efficiently collect those environmental data.

OBJECTIVES

The LEAR (Littoral Environmental Acoustics Research) 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. During FY08, research has been concentrated in the areas of data analysis and modeling. The objectives are:

1. Analyze mid-frequency propagation in shallow water in the presence of small ambient internal waves. Specifically, study the mean acoustics intensity field and its fluctuations. The significance of the work is that little has been done on this topic in shallow water environments where environmental measurements were also made to support adequate modeling effort. The effort is to support application of mid-frequency sonar in shallow water environments.
2. Analyze sediment sound speed data from in situ measurements using the SAMS (Sediment Acoustics Measurement Systems). The goal is to estimate sediment sound speed and its error bound to support modeling of mid-frequency sound propagation in shallow waters.
3. Short range (500 – 1000 m) propagation through internal waves – whether acoustic interaction with internal waves can be modeled using deterministic measurements of internal waves.
4. Long-range (10 km) mid-frequency sound propagation (collaboration with Henyey, Williams, and Yang).
5. Measurements of sediment roughness and sediment shell distributions to support bottom scatter and reverberation.

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14. ABSTRACT 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 that impact mid-frequency sonar performances in shallow water environments, and to develop means to efficiently collect those environmental data.					
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APPROACH

We successfully completed the comprehensive LEAR 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 propagation measurements at a short range of 500 m -1000 m over extensive time to collect statistics on sound field fluctuations. In this period, collaboration with oceanographers provided internal wave measurements in the acoustic path, making it possible to make deterministic model/data comparison. Then propagation measurements were made in two different days under similar conditions over a path to a range of 9 km to study long-range propagation by mid-frequency sound. As part of the large environmental measurements, we also actively participated in environmental measurements on in situ sediment sound speed and bottom roughness using SAMS and IMP2 combined with a laser scanner.

WORK COMPLETED

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

1. Model/data comparison of long range propagation of mid-frequency sound in shallow water. Mean intensity and intensity fluctuations have been analyzed, resulting in two publications [1-2] (collaboration with Henyey and Williams).
2. Analysis of SAMS in situ measurements of sound speed in three locations within the SW06 area with one publication [3] (collaboration with Yang and Williams).
3. Analysis of sound scattering by internal solitary waves with one publication [4] and one manuscript in preparation (collaborations with Rouseff, Henyey and Williams).
4. Analysis of seafloor roughness and sediment shell distribution from conductivity and laser scan measurements to support bottom backscatter modeling. One paper under review and one in preparation (Collaboration with Wang of Taiwan).

RESULTS

1. Mean Intensity: Mid-frequency sound propagation in shallow water was measured at multiple ranges along with extensive environmental measurements, especially 2D CTD measurements using a towed chain. These measurements provided the opportunity to quantify the statistics of transmission loss. It was found that most of the sound is trapped in the sound channel where water column variability dominated the acoustics field fluctuations. Because of the presence of closely packed caustics at convergence regions, ray theory cannot be used to accurately calculate sound intensity levels. The intensity was estimated from data and compared to an incoherent mode sum model. The comparison indicated that the mean intensity can be modeled to within 2 dB for most of the ranges and frequencies studied, but there were exceptions where the difference between model and data exceeded 4 dB. Although the differences between the model and data are small, they are statistically significant. Sufficient towed chain data were taken to allow a more detailed statistical model of the internal waves. We expect that Monte Carlo propagation calculations using this statistical model will more accurately describe the

data than the simple model presented. The data will also be used to check the validity of the transport theory, where certain approximations are made. While such a theory, when applicable, can be used to predict the statistics of the intensity, simulations based on the Parabolic Equation method are potentially a more reliable and general way to study mid-frequency acoustics propagation in complex environments. An important quantity for scientific understanding and applications is the coherent field, where phase coherence over time is measured. However, because the relative positions of the source and receivers were not known to sufficient precision during SW06, field coherence was not studied, but should be a high priority for a future field experiment.

2. **Intensity Fluctuations:** intensity fluctuations are due to water column sound speed variability from ambient internal waves. The data were collected on a day when there were no strongly nonlinear internal waves present. It is highly unlikely that fish scattering is the cause of the fluctuation because the observed large fluctuation requires high fish density. Also, such fish presence would result in noticeable attenuation in the mean intensity versus range, which is not observed. Two findings were not anticipated before the experiment: intensity is only correlated over a narrow frequency band (50–200 Hz) and the bandwidth is independent of center frequency and range; the intensity PDF peaks at zero for all frequencies, and follows an exponential distribution at small values. What causes the observed deep fades in intensity? Such deep fades manifest as uncertainty in predicting mid-frequency sound propagation in shallow water. To understand the intensity fluctuation in order to estimate uncertainty, two potentially profitable approaches are numerical simulations based on the parabolic equation approximation and transport theory such as the one proposed by Dozier and Tappert, where the validity of some key assumptions needs to be investigated.
3. **Sediment Sound Speed:** direct measurements of sediment sound speed using the Sediment Acoustic-speed Measurement System (SAMS) have been analyzed. Sediment data were taken at three positions. Sediment sound speeds and uncertainties are summarized. Results indicate a 20-m/s sound speed variation between two positions separated by a few hundred meters. The sediment sound speeds found at positions 1, 2, and 3 are 1618 ± 11 , 1598 ± 10 , and 1600 ± 20 m/s, respectively. Little dispersion in sediment sound speed was observed.

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) and high-frequency sediment acoustics (SAX04)

PUBLICATIONS

1. Tang, D., F. S. Henyey, Z. Wang, K. L. Williams, D. Rouseff, P. H. Dahl, J. Quijano, and J.W. Choi, "Mid-frequency acoustic propagation in shallow water on the New Jersey shelf: Mean intensity," *J. Acoust. Soc. Am.* **124**, EL85 (2008).
2. Tang, D., F. S. Henyey, Z. Wang, K. L. Williams, D. Rouseff, P. H. Dahl, J. Quijano, and J.W. Choi, "Mid-frequency acoustic propagation in shallow water on the New Jersey shelf II: Fluctuations," *J. Acoust. Soc. Am.* **124**, EL91 (2008).
3. Rouseff, D. D. Tang, K. L. Williams and Z. Wang, "Mid-frequency sound propagation through internal waves at short range with synoptic oceanographic observations," *J. Acoust. Soc. Am.* **124** EL73 (2008).
4. Yang, J., D. Tang, and K. L. Williams, "Direct measurement of sediment sound speed using SAMS in SW06," *J. Acoust. Soc. Am.* **124**, EL116 (2008).
5. Lynch, J. and D. Tang, "Overview of Shallow Water 2006 *JASA EL* Special Issue Papers," *J. Acoust. Soc. Am.* **124**, EL63 (2008).
6. Tang, D. J. N. Moum, J. F. Lynch, P. Abbot, R. Chapman, P. H. Dahl, T. F. Duda, G. Gawarkiewicz, S. Glenn, J. A. Goff, H. Graber, J. Kemp, A. Maffei, J. D. Nash, and A. Newhall, "Shallow Water '06: A Joint Acoustic Propagation/Nonlinear Internal Wave Physics Experiment," *Oceanography* Vol. 20, No. 4 pp156-167 (2007)
7. Henyey F., K Williams, and D. Tang, "Simultaneous nearby measurements of acoustic propagation and high-resolution sound speed structure containing internal waves," in preparation.
8. Wang, C. and D. Tang, "Seafloor Roughness Measurement by Laser Line Scanning and Conductivity Probe at SW06 Experiment Site," in preparation.
9. Wang, C. and D. Tang, "Estimating shell fragment distribution on the seafloor from images of laser scans," in preparation.