DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

Shallow Water Mid-Frequency Research and SW06

Dajun (DJ) Tang
Applied Physics Laboratory, University of Washington
1013 NE 40th Street, Seattle, WA 98105
phone: (206) 543-1290 fax: (206) 543-6785 email: djtang@apl.washington.edu

Award Number: N00014-08-1-0077
http://www.apl.washington.edu/projects/SW06/

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, as well as reverberation. 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 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 FY10, continuing FY09 effort, research has been concentrated in the areas of data analysis and documentation of results, as well as planning of a shallow water reverberation experiment. An important underlining emphasis going forward is to define what is needed to conduct a 6.1 reverberation experiment at the mid-frequency where environmental processes relevant to the reverberation modeling are also measured. The objectives are:

1. Analyze mid-frequency propagation data in shallow water in the presence of small ambient internal waves. Specifically, documentation of intensity field and its fluctuations (scintillation index). The significance of the work is that little has been done on this topic in shallow water environments. The effort is to support application of mid-frequency sonar in shallow water environments.
2. Comparison geoacoustic inversion results based SW06 propagation data to sediment sound speed data from in situ measurements using the SAMS (Sediment Acoustics Measurement Systems).
3. With a new DURIP fund, improving the SAMS to extend its capability to lower frequencies (700 Hz) in order to better understand sediment dispersion.
4. Modeling bottom ripple fields as a non-Gaussian process and studying its role in "clutter."
5. Development of an efficient modeling capability based on PE (Parabolic Equation) to model mid-frequency reverberation.

APPROACH

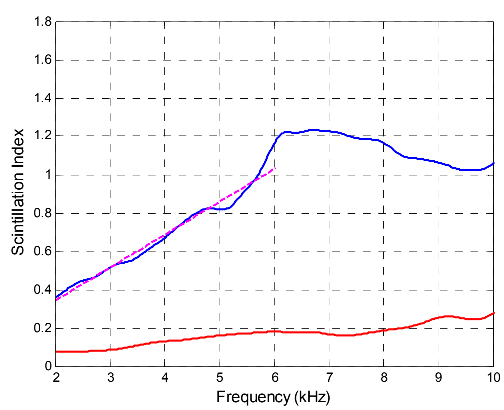
Because mid-frequency data in shallow water are limited, we continue to base our analysis and development of models on data sets collected in SW06 off the New Jersey coast, where both acoustics and environmental data are available. This is crucial for achieving the goal of quantitative model/data comparisons of sound fields interacting with bottom, surface, and the water column. Based on work from the previous two years, we made oceanographic models to predict sound propagation under the influence of internal tides. Another important area is the study of sound intensity fluctuation, where we identified a single arrival from other arrivals to quantitatively analyze the scintillation index. We also approached the mid-frequency problems theoretically in two topics: one is the modeling sediment ripple fields as a non-Gaussian process that can be a "clutter" mechanism; the other is formulating reverberation in a range-dependent environment by the combination of using the PE as the two-way propagator and perturbation theory for backscatter.

WORK COMPLETED

1. Geoacoustic inversion (collaboration with Yang and Jackson).
2. Mid-frequency intensity scintillation index analysis (collaboration with Rouseff, Henyey, and Yang).
3. Formulation and initial numerical implementation of Monte Carlo reverberation model based on PE and perturbation theory (with Jackson).

RESULTS

1. Scintillation Index. The figure below shows the measured scintillation index of a single arrival at 1 km range going through two upper-turning points as a function of frequency (blue). The red curve is scintillation of a bottom bounce arrival as a reference. The pink line is an estimate of the slope of the scintillation index as a function of frequency. The trend demonstrates that the scintillation index goes from under saturation, to over saturation (around 6 kHz) and saturation (9-10 kHz). It was previously anticipated that saturation would not happen at such short range. This result provides quantitative explanation to why match-field processing works better at low-frequency, where scintillation is low, but is problematic with increasing frequency. This result also provides an explanation for why low-frequency geoacoustic inversion techniques work better, because at low-frequency suffers litter intensity fluctuations, as can be projected from the figure. A paper on this topic is written.



2. A new model of reverberation capable of dealing with range-dependent environment is developed. The parabolic equation method is used to handle the two-way propagation, and first order perturbation theory is used to handle the backscatter. Because the calculation time is independent of the number of realizations, this method is much faster numerically than any models available. Another advantage is of this method is that it can easily handle complications such as internal waves and swells. Using this new model, we have investigated the effect of sediment ripples and internal waves as clutter mechanisms. Also investigated is how to compare this model to some Navy standard models to understand the compromise between fidelity and speed.

IMPACT/APPLICATIONS

We anticipate impacts in the following areas: first, the work on scintillation index will help open further research of sound wave propagation in shallow water as a problem of wave propagation in random media, linking shallow water research to that in the deep ocean, both managed by ONR's acoustics program. Second, the new reverberation model makes it possible to simulate a large number of shallow water reverberation problems. On the very top of our agenda, we would use the model to investigate the following hypothesis: shallow water clutter is due to the combination of forward scatter that diverts sound to higher grazing angles, and backscatter from these high angle incident energy.

RELATED PROJECTS

ONR reverberation workshop series (Thorsos and Perkins)

PUBLICATIONS

1. Tang, D., and D. R. Jackson, "Scattering from an arbitarily shaped rough interface embedded in heterogeneous fluids, " J. Acoust. Soc. Am., (In preparation).

2. Henyey F., K Williams, J. Yang, and D. Tang, "Simultaneous nearby measurements of acoustic propagation and high-resolution sound speed structure containing internal waves," *IEEE J. Oceanic Engineering* (in press).

3. Yang, J., D. Rouseff, D. Tang, and F. S. Henyey, "Effect of the internal tide on acoustic transmission loss at mid-frequencies", *IEEE J. Oceanic Engineering,* Vol. 35, 3-11 (2010).

4. Briggs, K. B., A. H. Reed, D. R. Jackson, and D. Tang, "Fine-Scale Volume Heterogeneity in a Mixed Sand/Mud Sediment off Fort Walton Beach, FL," *IEEE J. Oceanic Engineering*, Vol. 35, 471-487 (2010).

5. Tang, D. Kevin L. Williams, and Eric I. Thorsos "Utilizing high frequency acoustic backscatter to estimate bottom sand ripple parameters," *IEEE J. Oceanic Engineering,* Vol. 34, 431-443 (2009).

6. Tang, D. F. S. Henyey, B. T. Hefner and P. A. Traykovski, "Simulating Realistic-Looking Sediment Ripple Fields," *IEEE J. Oceanic Engineering*, Vol. 34, 444-450 (2009).

7. Wang, C. and D. Tang, "Seafloor Roughness Measurement by Laser Line Scanning and Conductivity Probe at SW06 Experiment Site," *IEEE J. Oceanic Engineering*, Vol. 34, 459-465 (2009).

8. Jackson, D. R., M. D. Richardson, K. L. Williams, A. P. Lyons, C. D. Jones, K. B. Briggs, and D. Tang, "Acoustic Observation of the Time Dependence of the Roughness of Sandy Seafloors," *IEEE J. Oceanic Engineering*, Vol. 34, 407-422 (2009).

9. Briggs, K. B., A. H. Reed, D. R. Jackson, and D. Tang, "Fine-scale volume heterogeneity in storm-generated stratigraphy in sandy sediment off Fort Walton Beach, Florida, USA," *IEEE J. Oceanic Engineering*, Vol. 35, 471-487 (2010).

10. 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).

11. 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).

12. 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).

13. 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).

14. Lynch, J. and D. Tang, "Overview of Shallow Water 2006 *JASA EL* Special Issue Papers,"J. Acoust. Soc. Am. **124**, EL63 (2008).

15. 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).