Reverberation, Sediment Acoustics, and Targets-in-the-Environment

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LONG-TERM GOALS

Develop and experimentally test target scattering models as well as reverberation/sediment-acoustic models. Quantitatively assess the modeling approximations possible within the fidelity/speed requirements of Navy performance estimators/simulators.

OBJECTIVES

Over at least the last few decades, much of the basic research effort related to ASW has focused on low-frequency propagation (the passive problem). Meanwhile, submarine technology has forced the Navy to increase its use of (low and mid-frequency) active sonar, in which case reverberation (including clutter) limits performance. Contemporaneously, active sonar MCM efforts have extended their frequencies of operation from high down to mid-frequencies. Again, in many cases, reverberation limits performance for these MCM systems. Thus the shallow water problem of acoustic scattering from a target in a waveguide, as well as character of the associated reverberation, continues to be both an applied and basic research problem of some significance over a broad range of frequencies.

My objectives are to:

1) carry out field measurements of shallow water reverberation and target scattering in the mid-to-high frequency range,

2) quantitatively predict these experimental results using a combination of exact finite element modeling, approximate numerical modeling, and analytical physical acoustics modeling.

3) determine the approximations possible within performance-prediction/mission-planning requirements.

APPROACH

The foundation of the reverberation and target scattering research are experiments planned for FY13-14. These experiments involve measurements of target and sediment backscattering as well as

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reverberation. The main experiment will occur off the coast of Florida in FY13 at a shallow water, sand bottom site. A second, more target oriented experiment will occur in FY14 in a shallow water, muddy site. A major goal of the experiments is to measure both the acoustics and the environmental conditions needed as input to models designed to predict the acoustic results. (These experiments are made possible by leveraging a combination of funds from the ONR Ocean Engineering, ONR Ocean Acoustics and SERDP Munitions Response teams.)

Reverberation

Finite element, ray based and energy transport based models of shallow water propagation and reverberation will be compared to the experimental data. The acoustic and contemporaneous environmental measurements will focus on supporting quantitative data/model comparisons in the 3-4 kHz range but will include data taken from 1-10 kHz.

Targets-in-the-environment response (TIER)

The target scattering experiments will cover the frequency range from about 1 to 50 kHz. A variety of targets, to be specified by the sponsors, will be placed in view of a rail/tower system that takes data at a sufficient resolution to produce synthetic aperture images of the target or, alternatively, to develop images of the target strength as a function of frequency and angle of observation. Finite element models (in combination with various physical acoustics based approximations) of the elastic response of these targets will be developed and compared to the data.

Sediment Acoustics

This effort is more model-focused with the corresponding experimental data already in hand from previous ONR work, i.e., SAX99 and SAX04. Data, from those experiments, on sediment sound speed, attenuation and scattering have indicated deficiencies in current sediment models at both low (below 3 kHz) and high (above 150 kHz) frequencies. The approach here will be to examine two physical effects that to this point have not been introduced into the model. At low frequencies this involves the thermal conductivity of the media and at high frequencies its non-continuum nature. This effort will initially take a back seat to the experimental preparations needed to address the first two avenues of research.

WORK COMPLETED

Reverberation

Field testing of the SAMS system of Dajun Tang allowed the opportunity for acquisition of reverberation data in the same area as where the FY12/13 efforts will be carried out. The source levels and other equipment limitations allowed for reverberation results out to 1.5 km. Various models (normal mode, Gaussian ray bundle, energy transport) have been compared to this data as a way to make sure we begin to understand and focus on critical path items from both a hardware and software standpoint as well as assessing the challenges our model development and model to data comparisons.

Targets-in-the-environment response (TIER)

APL/UW and NSWC PCD personnel have finalized the requirements for the integration of NSWC PCD sources and receiver into the rail/tower system. The location, time of year and UNOLS ship decisions have been finalized for the engineering tests of this new integrated system. A preliminary test plan has been developed and will be discussed with NSWC PCD research and test personnel in October. The experiment will be conducted about a mile off shore from Panama City Florida using the R/V Sharp from April 17^{th} to April 28^{th}

Finite element modeling results have been compared to experimental results from the PONDEX10 experiment. Developments have allowed model/data comparisons for conditions we previously have felt were problematic given the modeling technique [1].

RESULTS

Reverberation

Figure 1 shows reverberation results from the experiment in April 2011. The reverberation has been multiplied by range cubed in order to get an approximately flat dynamic range. The data is beamformed from a 32 element horizontal array and the center frequency is 3 kHz.

The range on the left hand side of the figure is restricted to 0.1 km in order to look at the area near the receive array. The high reverberation region circled in black is scattering from the research vessel R/V Sharp. The high reverberation area circled in blue has not been uniquely identified at this point. On the right hand side reverberation out to 1.5 km is shown. The data allowed 1000 such images to be formed separated by 5 seconds. Viewing a movie of these images indicated that the high reverberation area circled in red was a constant feature (probably associated with some object on the bottom) while the one circled in blue was apparent in only a couple of the images and appeared to move (probably volume scatterers, e.g., fish). Many images showed similar transitory high scattering regions. The region circled in black is an artifact from the transmitter due to limitations on eliminating left/right ambiguity.

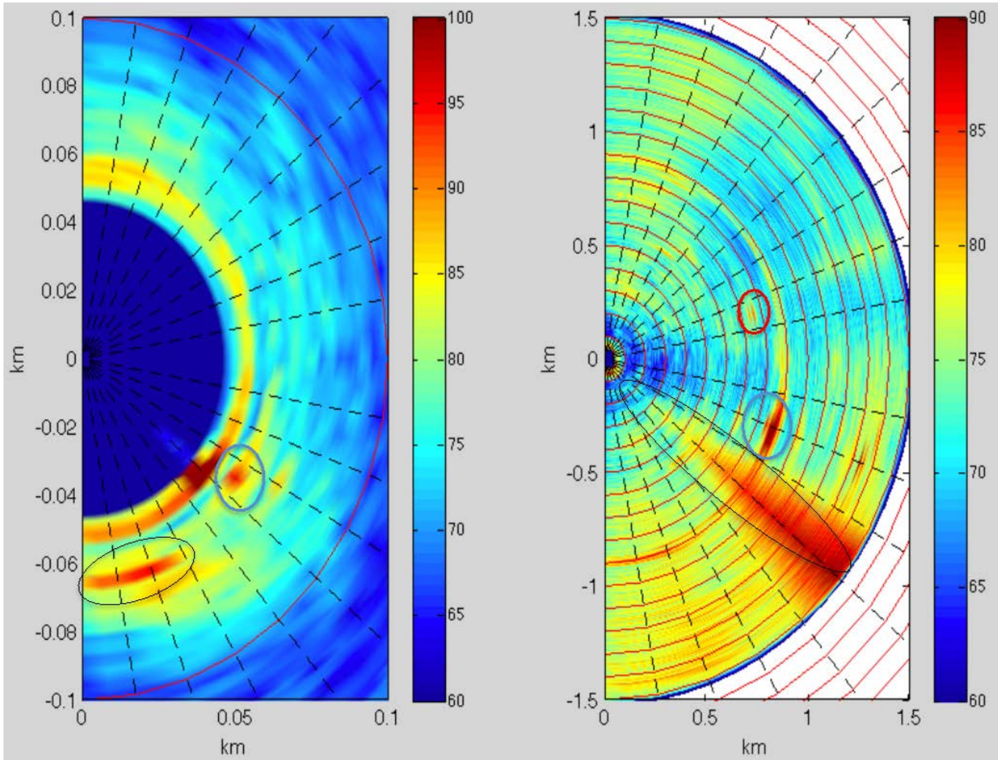

Figure 1. Reverberation at 3 kHz (multiplied by range cubed) derived from data taken off Panama City, Florida in April 2011.

Figure 2 shows an ensemble result for the reverberation received on one element of the horizontal array. The low source level restricted the time window for which reverberation could be examined for an individual element. The mean ambient noise level was subtracted from the receive data in order to examine reverberation levels out to 2 seconds. Several different models are compared to the data. The model results are consistent with each other but fall several dB below the data. Current efforts center around confirming sensor calibrations, enhancing the experimental hardware to allow absolute reverberation measurements out to 8-10 seconds and establishing sensitivity to various environmental parameters.

Targets-in-the-environment

An example of data/model comparison is shown in Figure 3. The target is a Aluminum bullet shaped target machined to mimic the shape of a specific Unexploded Ordinance (UXO). It is deployed proud on a sand sediment. The panels on the right are the absolute target strength as a function of angle (vertical axis) and frequency (horizontal axis). Establishing the comparison seen in the two panels on the right hand side was an iterative process that brought to light the need to make sure sufficient time windows were used to allow high Q features to be seen. The panel on the left shows experimental results for two different time windows, the short time window reduced noise but limited the Q too much to allow valid data/model comparison.

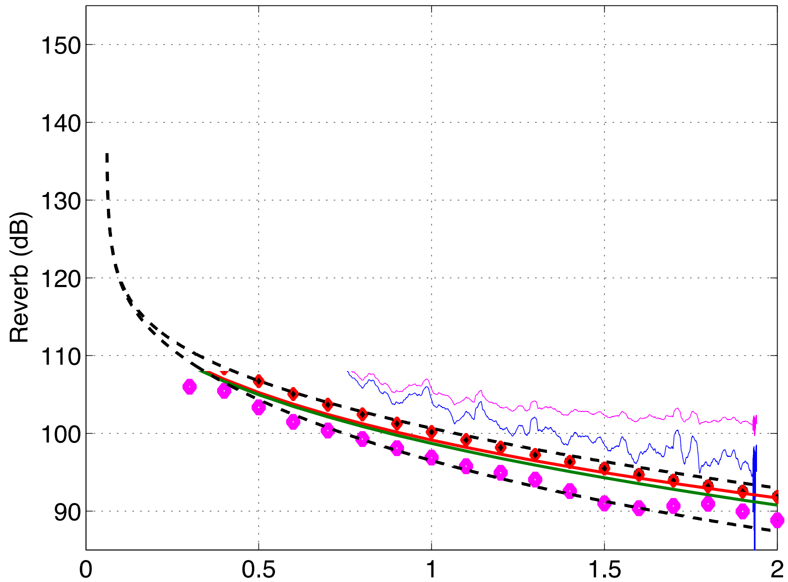

Figure 2. Reverberation measured on one element of the receive array from the April 2011 experiment.

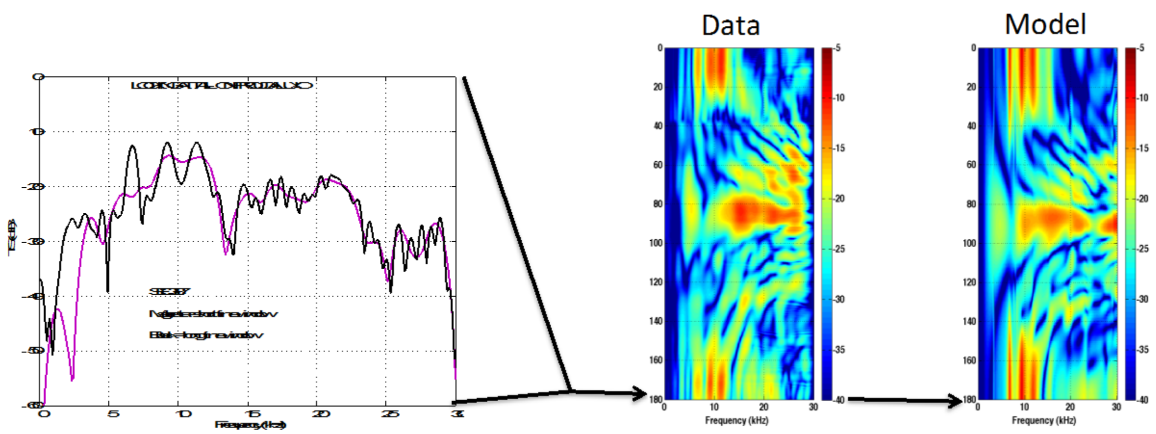

Figure 3. Data model comparisons are shown for a target deployed on a sand sediment. The model uses a combination of finite element analysis near the target and Helmholtz integration away from the target. The left hand plot is a single angle slice from the data panel in the center

IMPACT/APPLICATIONS

Active ASW and MCM at mid-frequencies (1-10 kHz) is a mainstay of the US Navy. Modeling to predict Signal-to-Noise ratios and target signatures in the Ocean are thus of primary importance. The results of the modeling carried out and the experimental validation of these models can feed directly into the next generation of Navy models used in TDAs and mission planning tools.

RELATED PROJECTS

"Influence of Variation in Sediment Conditions on the Acoustic Response of Targets near the Sea Floor," ONR Grant N00014-10-1-0394, PI: A.L. Espana.

"High Fidelity Finite Element Modeling for the Identification of Low- to Mid-Frequency Proud and Buried Object Elastic Responses and SAS Image Features," ONR Grant #: N62909-10-1-7153, PI: M. Zampolli

"Acoustic Color of mines and mine-like objects: Finite Element Modeling (FEM), Developing Automatic Target Recognition (ATR) strategies, and at-sea experimental validation," ONR Contract #: N00014-07-G-0557/0032, PI: K. L. Williams (APL-UW).

"Full Scale Measurement and Modeling of the Acoustic Response of Proud and Buried Munitions at Frequencies from 1-30 kHz," SERDP Contract #: W912HQ-09-C-0027, PI: S. G. Kargl

REFERENCES

[1] M. Zampolli, A. L. Espana, FY11 ONR year end report, "High Fidelity Finite Element Modeling for the Identification of Low- to Mid-Frequency Proud and Buried Object Elastic Responses and SAS Image Features".

PUBLICATIONS

J. R. La Follett, K. L. Williams, P.L.Marston, "Boundary effects on backscattering by a solid aluminum cylinder: Experiment and finite element model comparisons," *J. Acoust. Soc. Am.,* 130, 669 (2011)

M. Zampolli, A. L. España, K. L. Williams, S. G. Kargl, E. I. Thorsos, J. L. Lopes, J. L. Kennedy, and P. L. Marston. "Low- to mid-frequency scattering from elastic objects on a sand sea floor: Simulation of frequency and aspect dependent structural echoes." J. Comp. Acous., (submitted Aug. 2011)