

Modeling of the Shallow Water Reverberation Statistics for ONR ASIAEX Experiment

Yevgeniy Dorfman
BBN Technologies – a Verizon Company
10 Fawcett St., Cambridge, MA 02138
phone: (617) 873-3173 fax: (617) 873-2918 email: edorfman@bbn.com

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LONG-TERM GOALS

The long-term goal is adaptive environmentally aware active sonar design and performance enhancement in shallow water through a better understanding of bottom reverberation, which is a major source of active sonar interference.

OBJECTIVES

The objective of this research is to study bottom reverberation as observed during the recent ONR Asian Seas International Acoustics Experiment (ASIAEX). The ASIAEX experiment provides an excellent data set to study monostatic reverberation, because:

- High quality environmental support information was collected in preparation for and during ASIAEX.
- Signals were received on a vertical line array (VLA) that spanned almost all of the water column. VLA receivers provide spatial selectivity in the vertical plane, which is very useful to resolve reverberation mechanisms (i.e., separate surface and bottom contributions).

The specific objective of the current work is to invert reverberation data obtained during the summer 2001 ASIAEX in the East China Sea in order to empirically recover bottom scattering strengths as a function of frequency and scattering angle. The ultimate objective is to infer scattering mechanisms responsible for low frequency bottom scattering in shallow water.

APPROACH

Shallow water monostatic reverberation is a combination of propagation effects coupled with scattering effects at different incidences and scattering angles from inhomogeneities present in the environment (such as those within the water column, bottom/sub-bottom roughness, ocean surface roughness, and bubbles entrained under the ocean surface).

A normal mode approach based on the inversion for the environmental parameters [1] was used to remove propagation effects from the received signal. In downward refracting channels, surface scattering typically contributes less to the overall reverberation than do bottom and sub-bottom scattering, because under downward refraction conditions, incidence and scattering angle are much

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larger at the bottom than at the surface, and scattering increases with increasing incidence and scattering angle. Thus scattering mechanisms for downward refracting shallow water channels are a combination of bottom scattering (roughness of the sediment-water interface) and evanescent field scattering by volume scatterers just below the interface (e.g., [2]). However, under higher sea states and/or for low-scattering bottoms, the relative contribution of the surface scattering may increase. Thus, an essential part of our approach involves using a VLA receiver to separate bottom and surface contributions and to determine empirical bottom scattering strength. As a next step, a model-based approach is necessary to separate bottom and sub-bottom contributions.

WORK COMPLETED

During FY02 initial plans were formulated at the Maui ASIAEX International Symposium in early November '01 for obtaining and using reverberation data obtained during the ASIAEX East China Sea experiment by Institute of Ocean Acoustics (Chinese Academy of Sciences) investigators under the leadership of Profs. Jixun Zhou and Renhe Zhang. A memorandum of understanding for sharing and use of the reverberation data was subsequently finalized at the Seattle ASIAEX East China Sea Post-Experiment Meeting in late January '02 and the reverberation data were distributed to Cable, Dorfman, and Knobles in mid April '02. Since then Cable, Dorfman, and Knobles have collaborated, working with the IAO reverberation data and with ASIAEX ECS transmission data obtained by Jim Miller, Gopu Potty (URI), and Peter Dahl (APL/UW), as well as with other East China Sea data sources. A preliminary analysis of ASIAEX monostatic reverberation data was conducted to infer empirical bottom scattering strength (SS). Initial forward transmission results were used to determine scattering strength. Using beamforming on VLA bottom and top sub-apertures, bottom contribution was isolated from surface contribution. Reverberation was analyzed in VLA beams to provide SS as a function of scattering angle. Higher order statistics of reverberation signals were also analyzed.

RESULTS

Three papers were accepted for the First Pan-American/Iberian Meeting on Acoustics in Cancun, Mexico, 2-6 December 2002. These papers are:

- “Analysis of time series data in the East China Sea generated from explosive sources” (Knobles, et al.), which, by inversion determines bottom geoacoustics and forward propagation
- “Mechanisms for the Asian Sea International Acoustics Experiment East China Sea reverberation measurements” (Dorfman, et al.), which determines the ASIAEX ECS bottom scattering strength values and their frequency and grazing angle dependence
- “Comparison of East China Sea low frequency bottom scattering strength determinations” (Cable, et al.), which compares scattering strength determinations obtained in ASIAEX ECS with those obtained by the HEP and MAASW(DT) program data and indicates theoretical implications of results.

Reverberation statistics were analyzed using a quasi-stationary model of the reverberation signal. Under this assumption, the mean value of the received signal is non-stationary, but the signal can be stationarized by removing the estimate of the mean value. For demeaned signals due to explosive sources in shallow water, Gaussian statistics are expected (e.g., [3]). In our processing, normalization

was such that the standard deviation was set to unity. The results are shown in Fig. 1 below. It is clearly seen in the figure that reverberation statistics are Gaussian (as expected), so signal is completely defined by the time-variable standard deviation (or mean value of its envelope).

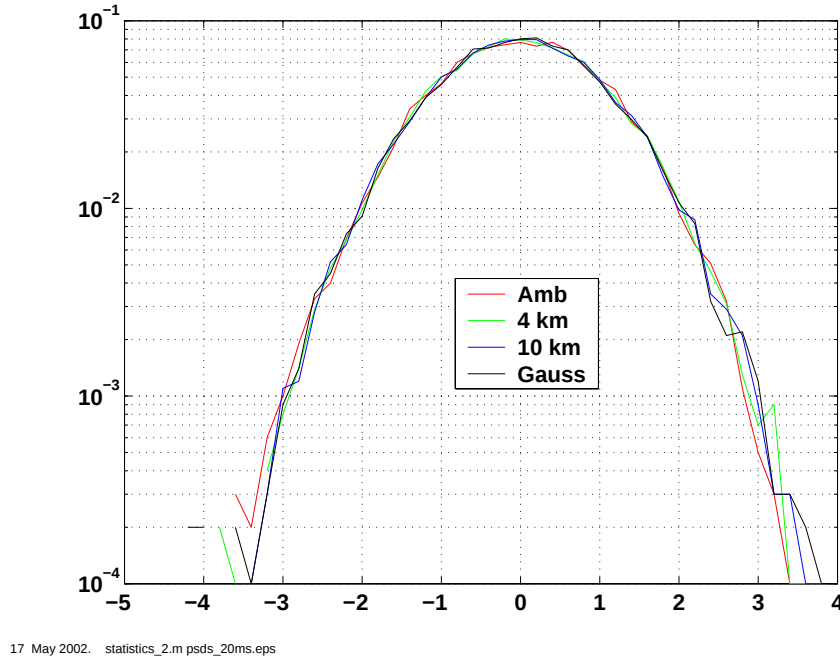
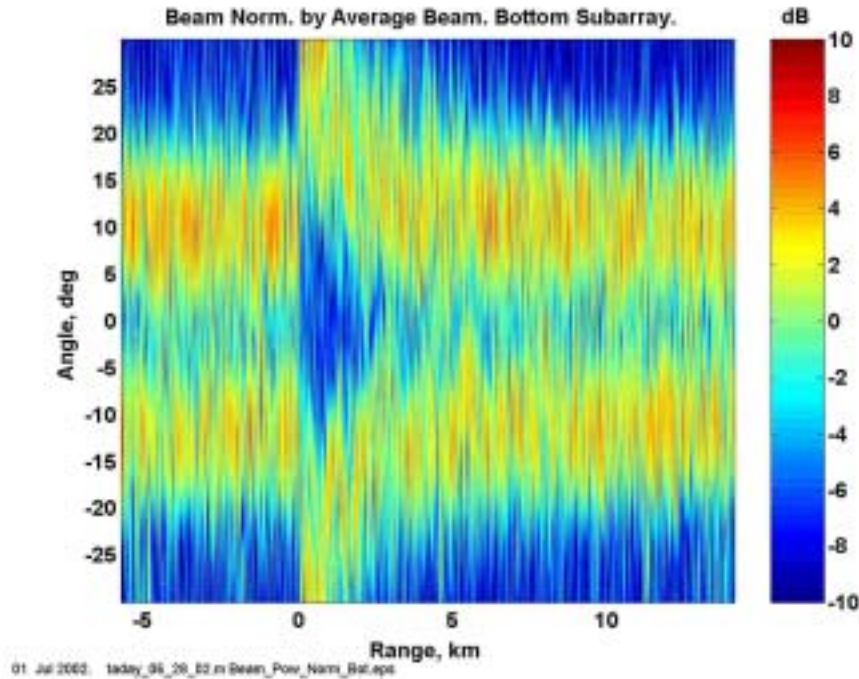


Fig. 1. Estimate of Probability Density Function (PDF) in demeaned reverberation signal recorded during the ASIAEX experiment. Green line: PDF estimate of reverberation signals originated at 4 km range. Blue line: PDF estimate of reverberation signals originated at 10 km range. Red line: PDF estimate of ambient noise recorded prior to the source onset. Black line: PDF of Gaussian random signal (generated with Matlab randn.m function) – shown for comparison.

An example of array processing (beamforming) using VLA is shown in Fig. 2 for signals in the octave band centered at 250 Hz. Figure 2 results are normalized by horizontal (0°) beam. The figure shows that returned reverberation signal increases as the array is steered away from horizontal direction for steering angles up to about ± 15 - 20° . This is attributed to the increase in scattering strength with increasing scattering angle. For steering angles larger than $\pm 20^\circ$, the received signal decreases (steep angles not supported in the shallow channel).

To infer bottom scattering strength from reverberation strength observed in the received signal, the signal must be corrected by transmission loss and ensonified bottom area, which is still a work in progress.



*Fig. 2. Beamformer output, bottom subarray (spanning bottom 30 m of the water column).
Vertical axis: steering angle, degrees, positive angle is up.*

IMPACT/APPLICATIONS

Bottom reverberation is a major factor limiting active sonar performance in shallow water. Better understanding and predictive modeling of bottom reverberation will aid in active sonar design, optimization, and performance and tradeoff studies.

TRANSITIONS

Empirical data on bottom scattering strength could transition to Navy acoustic databases. Bottom reverberation models can transition to Navy tactical decision aids for low frequency shallow water active systems such as IEER and Distant Thunder (DT).

RELATED PROJECTS

This research is being conducted jointly with Peter Cable (BBN, Washington) and David Knobles (ARL:UT). Long-range reverberation ASIAEX studies of Renhe Zhang and Jixun Zhou have responsibility for the data that will be used in the present research.

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