Studies on Sonar Clutter and Reverberation

John R. Preston
Applied Research Laboratory
P.O. Box 30
State College, PA 16804
phone: (814) 863-1310   fax: (814) 863-8783   email: preston@ciao.arl.psu.edu

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http://www.arl.psu.edu

LONG-TERM GOALS

The long-term goals of this effort are to:

- Assess capability of directional arrays for inversion and reverberation studies

- Characterize acoustic clutter in a manner that will lead to its mitigation

- Improve geo-acoustic parameter extraction from reverberation data

- Construct suitable high fidelity reverberation and scattering models for model/data comparison and inversion

OBJECTIVES

The objectives of this effort are to:

- Use and continue to collect cardioid data from FORA and the NURC cardioid arrays, conduct cross frequency correlation studies of scattering features to assess the utility of this technology for reverberation and clutter analysis both in the cardioid frequency band and at lower frequencies.

- Continue the use of K-distribution-based techniques of Abraham to statistically characterize the various types of clutter seen on STRATAFORM especially the bio-clutter data from FORA.

- Continue validation and improvement efforts on a new reverberation model and the automated geo-acoustic parameter extraction technique from reverberation data.

- Operate, maintain and improve FORA hardware and data acquisition systems. Help plan and participate in ocean experiments in support of sea floor scattering, sonar clutter studies and ocean reverberation experiments.

APPROACH

There is a 4-year Joint Research Program (JRP) with NURC, ARL-PSU, NRL, and DRDC Atlantic, of Canada. It is called Characterizing and Reducing Clutter in Broadband Active Sonar. Experiments are being designed to support the JRP (the PI is a member of this JRP). The most recent experimental

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14. ABSTRACT
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effort, called CLUTTER07, took place near the Malta Plateau area in May of 2007. It was focused on the physics based and the statistical characterizations of acoustic clutter for lower frequency sonars. The Five Octave Research Array (FORA) was one of two primary receivers for this experiment as well as for the BASE07 sea trial that immediately followed it.

The cardioid array section at the head of the FORA offers an improved way to study reverberation and scattering in shallow water. Some FORA cardioid data was collected in the 2006 Gulf of Maine experiment near Georges Bank, and a much more extensive set was taken in the 2007 CLUTTER07 and BASE07 experiments on the Malta Plateau. In addition much data has been taken using the NURC cardioid array in the same 2007 experiments and in the Boundary 2004 experiment on the Malta Plateau. These data are serving to test and improve the beamforming algorithms and data processing tools needed to better understand reverberation and scattering from towed arrays. The NATO Undersea Research Centre has shown examples of left-right rejections in excess of 15 dB on its cardioid array (NURC report SR-329A by D. Hughes). Recently the PI has verified that similar performance was observed using FORA . Studies on wider band beamforming algorithms will be a focus of analysis on the 2007 data sets. It well known that often the same reverberation features can be observed over a wide range of frequencies. Objectives for this task are to continue to correlate the high frequency unambiguous feature information from the cardioid data with the lower frequency bearing ambiguous information from line arrays and to define the circumstances under which good cross-frequency correlations exist.

The PI completed an initial effort to statistically characterize the clutter seen on STRATAFORM in the 2001 Acoustic Clutter Reconnaissance Experiment (ACRE) using methods developed by Abraham. Results, showed many data segments of matched filtered amplitudes to be non-Rayleigh and that the bistatic data were significantly more non-Rayleigh than the monostatic data. The non-Rayleigh behavior is consistent with the spikiness seen in much of the 2001 ACRE polar displays. Much of the observed statistical differences between various data segments can be explained by considering differences in multipath, amounts of bottom insonification and the overall sound speed structure. New work on the 2003 STRATAFORM data showed reverberation there to also be very non-Rayleigh (median shape parameters approximately unchanged from 2001). However, they had larger average scatterer size, which was consistent with observed fish schools that were more massive than in 2001. This work will be extended to include a statistical characterizations of the fish dominated scattering vs. the bottom-dominated regions to try to discriminate the two different types of clutter.

In the past the towed array based inversion algorithms developed by the PI used bearing ambiguous diffuse reverberation data and therefore were not able to map extracted geo-acoustic parameters in more than a spatially averaged sense when reverberation was anisotropic. New inversion work using directional cardioid data should be evaluated for the expected improvement in inversion quality vs. bearing.

A new faster and simpler range-dependent reverberation model is in development (together with Dale Ellis of DRDC who is working jointly with the PI) and will serve as the forward model engine for the simulated annealing based inversion scheme already in use. It is expected that refinements to that model will continue under this effort. Examples from the new reverberation model were presented at the 2006 ONR Reverberation Modeling Workshop in Austin, TX and in more detail at the 2007 Underwater Acoustics Measurements (UAM) Conference in Crete.

WORK COMPLETED

Under cardioid data analysis a recent paper by the P. I. (Journal of Oceanic Engineering, Oct. 2007), presented some directional characteristics of observed clutter and reverberation using triplet arrays. He showed there is usable left right discrimination down to ~600 Hz using the NURC triplet array. Also shown was that the Hughes cardioid beamforming algorithm has an upper frequency limitation. In that paper the P. I. also derived the normalization terms needed to provide calibrated levels out of cardioid arrays.

Together with D. Ellis, the P. I. was invited to submit two journal articles on our Rapid Environmental Assessment (REA) techniques using reverberation. The work is a compendium of our joint work from 1996 to 2004 and so we felt it was important to document our efforts in a peer reviewed journal (see references). A fair amount of effort was spent to prepare these manuscripts and answer reviewer comments.

Efforts to develop a range dependent normal mode based reverberation model (in collaboration with D. Ellis of DRDC) have continued. Westwood's ORCA (JASA 1996) is used to generate the eigenvalues and eigenfunctions for an environment and then modifications to Ellis' techniques (JASA 1995) have been used to build the reverberation model using MATLAB. Some results were presented and submitted at the two ONR Reverberation Modeling Workshops held in 2006 and 2008 and also at the 2007 Underwater Acoustics Measurements (UAM) Conference in Crete. The most recent efforts have been focused on adding the time spread and dispersion corrections used by Ellis (JASA 1995) to the model. The next step will be to implement the adiabatic normal mode formulation [3] for weak range dependent problems.

Using some 2004 reverberation data, the P. I. has recently helped Charles Holland to extract selected time series and other characteristics used in computing target strengths from mud volcanoes and other clutter sources on the Malta Plateau (JASA, 2007).

Also the P. I. was an organizer for the International Symposium on Underwater Reverberation and Clutter held by NURC in Italy (Sept. 2008). The P. I. was author or co-author on three papers [1–3].

In this time period, additional new pieces of software have been developed by the P. I. to batch beamform data from the FORA. This is a step up in our ability to provide FORA users more useful products. Copies of raw and beamformed and match filtered data are being provided to other JRP researchers as part of the P. I. s FORA responsibilities.

The P. I. has also spent some effort in overseeing the 'care and feeding' of the ONR FORA at Penn State in preparation for the 2009 NPAL/SPICE/LOAPEX experiments with M.I.T. In addition a FORA refurbishment effort is fully underway that has required a fair amount of oversight. This effort was funded under a new DURIP to outfit FORA with an Instrumented Tow Cable (ITC) capability (effectively like a built in thermistor chain) using a brand new array tow cable. Other modifications include new FORA acquisition computers and understanding and minimizing any data latency or synchronization issues.

RESULTS

Figure 1 shows a reverberation vs. time model-model comparison at 250 Hz between the P. I.'s new ORCA-Matlab based reverberation model and the NOGRP model of Ellis. A problem from the first

ONR Reverberation Modeling Workshop was modified to illustrate the effects of modal dispersion on the estimate for reverberation. A scatterer was inserted at 20 km range which was modeled as a azimuthally symmetric with a scattering strength 20 dB higher than the MacKenzie -27 dB background but only for a range extent of 100 m. The model-model match between this model and the NOGRP prediction of Ellis seems quite reasonable.

Figure 2 shows a model prediction of reverberation and target echo vs. time at 250 Hz from the P. I.'s new ORCA-Matlab based reverberation model for problem T from the second ONR Reverberation Modeling Workshop. This shows the estimated echo spreading from a 5 m diameter sphere 10 m from the surface as well as the predicted background reverberation from both this model and Ellis' model.

IMPACT/APPLICATIONS

A better understanding of sonar clutter is key to improving sonar performance in shallow water. The new FORA and NURC cardioid arrays are exciting new tools for ocean acoustic researchers. A wide area-averaged bottom parameter estimation technique such as described above and that utilizes directional reverberation measurements could provide a quick way to estimate bottom parameters and hence give improved sonar performance estimates.

TRANSITIONS

Inversion techniques similar to those described above have recently been applied to select data from recent HEP experiments as part of ONR 6.2 efforts led by Dr. R. Wayland in support of the TAMBDA program at NAWC. In addition, an effort is underway to incorporate the above inversion concepts and reverberation models into a multi-static parallel toolbox – an effort that is being led by J. Joseph at NAWC.

The 2007 CLUTTER07 and BASE07 experiments on the Malta Plateau have produced a large quantity of high quality data that will help ONR researchers to understand and eventually mitigate sonar clutter.
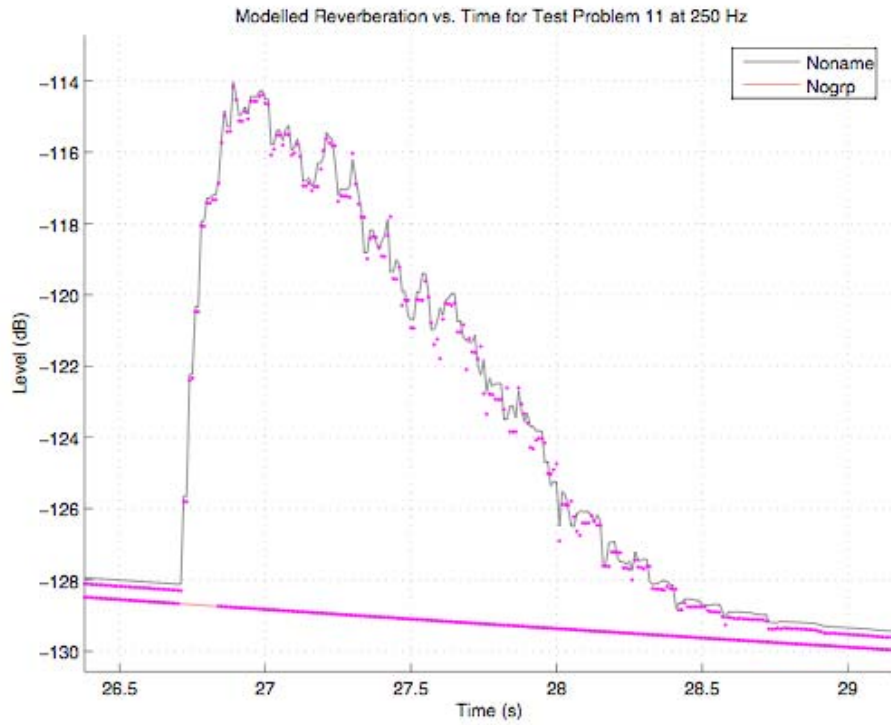
Fig. 1. Model-model comparison of time spread for a discrete scatterer embedded in test prob. 11 for the first ONR Reverberation Modeling Workshop.
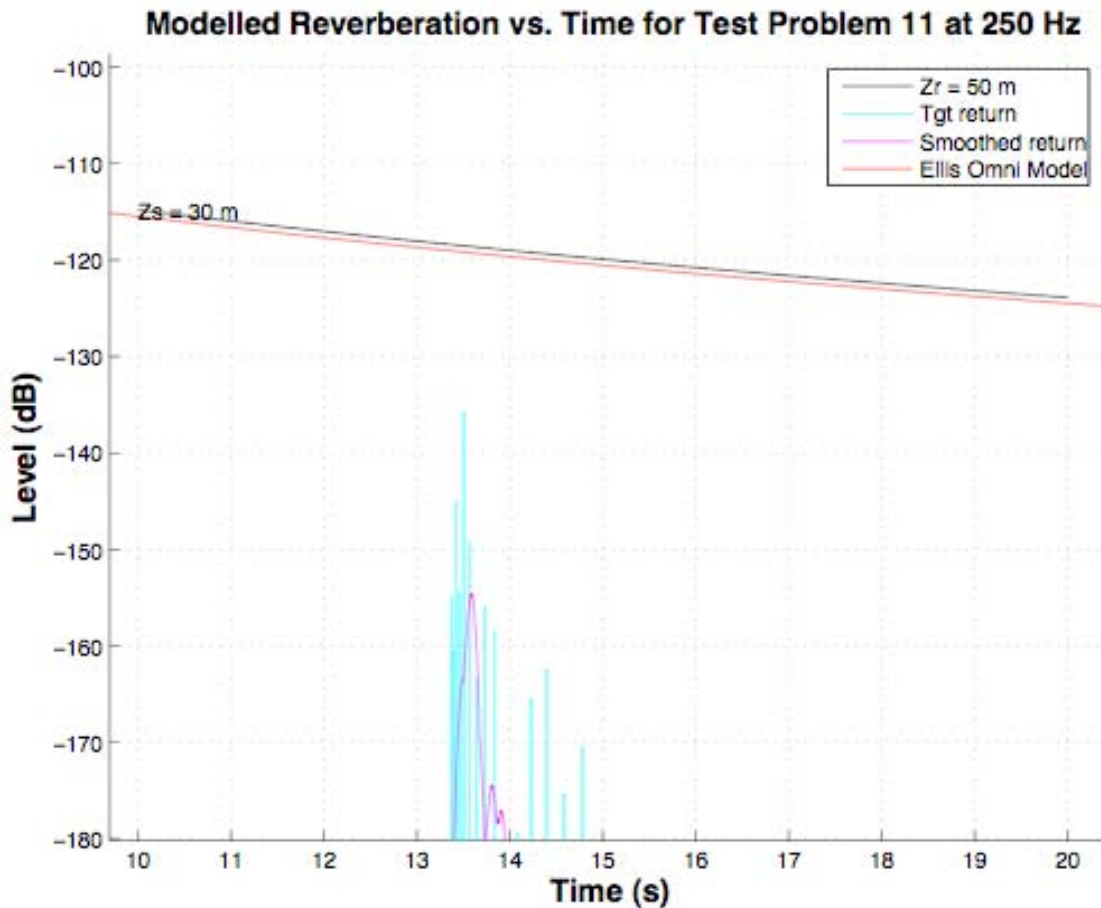
*Fig. 2. Model estimated echo for test problem T of
the second ONR Reverberation Modeling Workshop.*

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