

Measurements and Analysis of Reverberation, Target Echo, and Clutter

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LONG-TERM GOALS

The long-term goal of this work is to better understand and model reverberation and clutter in shallow water environments, and to develop techniques for Rapid Environmental Assessment (REA) and environmentally adaptive sonar.

OBJECTIVES

The current project is a joint collaboration between Defence Research & Development Canada – Atlantic (DRDC Atlantic) and the Applied Research Laboratory of The Pennsylvania State University (ARL/PSU) to analyze and model reverberation, target echo, and clutter data in shallow water. It allows the PI to spend approximately three months each year at ARL/PSU. The collaboration leverages programs in Canada, US, and a joint research project with the NATO Undersea Research Centre (NURC). The primary effort is analysis and interpretation of data, together with development and validation of improved modeling algorithms. One focus is the performance of directional sensors in towed arrays. The PI participated in the Clutter '07 and BASE '07 Mediterranean sea trials with NURC, and the data from it and other sea trials are being analyzed. A fast shallow water sonar model that includes target echo and clutter is being developed and validated. Models are being validated as part of the ONR Reverberation Modeling Workshops.

APPROACH

The PI spends three months per year at ARL/PSU, conducting joint research primarily with Drs. John Preston and Charles Holland. DRDC Atlantic generally funds Dr. Preston for two weeks of research in Canada. Additional collaboration takes place throughout the year. The main objective of this collaboration is to analyze, model, and interpret data received on towed arrays during reverberation and clutter sea trials. The primary outputs of the collaboration are manuscripts for joint publications in refereed journals. Secondary outputs are improved models and algorithms.

Foci of this collaboration are Joint Research Projects (JRPs) between NURC, Canada, and several US research laboratories (ARL in particular). The current JRP is “Characterizing and Reducing Clutter for Broadband Active Sonar”. The most recent trial was Clutter '07, which took place on the Malta Plateau in May 2007. A second trial BASE '07 took place in the same area. The PI participated in the Clutter trial, and the first part of the BASE trial.

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This project emphasizes examination and interpretation of data from several towed arrays with directional elements – specifically the NURC and ONR cardioid arrays with triplets of omnidirectional elements and the DRDC DASM (Directional Array Sensor Module) array with omnidirectional plus dipole sensors. Models are being extended to compare the performance of these arrays. Data from the Boundary '04, BASE '04, Clutter '07, and BASE '07 are being analyzed along the lines of previous experiments [Preston/Ellis, 1999, 2001; Hines et al., 2001; Preston et al., 2005; Holland et al., 2005].

As part of the analysis, a fast shallow-water reverberation model [Ellis, 1995] based on normal modes [Ellis, 1985] is being extended to a fast shallow-water “sonar” model that includes target echo and feature scattering [Ellis et al., 1997; Ellis and Pecknold, 2006; Ellis, 2007]. Like the reverberation model, it will be computationally-efficient and include the 3-D effects of towed array beam patterns [Ellis, 1991], signal excess, and time-spreading in order to compare with experimental measurements. The objective is to quantitatively invert, not just for bottom loss and scattering [Ellis and Gerstoft, 1996; Ellis et al., 2000; Preston 2001, 2002], but for the strength of various clutter features. The model will also be validated against more computationally-intensive “physics-based” models developed by other researchers.

The ONR Reverberation Modeling Workshops have been a more recent focus for collaboration. The PI extended and exercised two of his models on a number of problems, and collaborated with Preston in developing a Matlab-based model using the Ellis [1995] normal-mode formulation. Other collaborations with Holland and Ainslie are leading to presentations at a Special Session of the Acoustical Society of America in November 2007, and journal publications are in progress. The PI is a member of the problem definition committee for the second Reverberation Modeling Workshop planned for March 2008.

WORK COMPLETED

The PI participated in the Reverberation Modeling Workshop in Austin in November 2006. He applied his normal mode models OGOPOGO/NOGRP to a number of problems, and collaborated with Preston in developing a Matlab-based model using the Ellis [1995] normal-mode formulation. Results were submitted in March for publication in the Workshop Proceedings [Ellis, 2006, 2007]. Follow-on collaborations with Ainslie and Harrison (See more details in the Results section below). are leading to presentations at a Special Session of the Acoustical Society of America in November 2007, and a journal publication is being prepared.

In collaboration with John Preston a bistatic version of the fast normal-mode approach was implemented using the ORCA normal-mode model [Westwood et al., 1996] together with Matlab scripts for the reverberation calculations. Results were presented at the ONR Reverberation Modeling Workshop in 2006, and at the Underwater Acoustic Technologies conference in 2007 [Preston and Ellis, 2006, 2007].

The normal-mode reverberation model was extended to handle scattering from a sub-bottom interface. Collaboration with Charles Holland has led to a comparison of the normal-mode and energy flux approaches. A paper has been submitted to the Journal of Computational Acoustics [Holland and Ellis, 2007], and some results will be presented at the Special Session on Reverberation Modeling at the November 2007 meeting of the Acoustical Society of America [Ellis and Holland, 2007].

Work has continued on extending the fast reverberation model to handle target echo and signal excess, including the effects of time spreading. An invited presentation [Ellis, 2007] was given at the 8th International conference on Theoretical and Computational Acoustics in Crete in July 2007. (The Results section below illustrates some time spreading effects).

The PI sailed on R/V Oceanus for the Clutter '07 sea trial and the first portion of the BASE '07 sea trial. Emphasis was on data acquisition, so it was not possible to analyze much data. However, the PI became familiar with the FORA processing chain, identified problems with some of the matched filter designs; he also developed a Matlab procedure for easily overlaying data on contours and clutter features. (The Results section shows an example using data from the Boundary 2004 experiment).

Work continued on comparing the effects of linear and triplet arrays on reverberation measurements. An invited paper was presented at the Underwater Acoustics Measurements, in Heraklion, Greece, in June 2007 [Ellis and Preston, 2007].

The September 2007 REA Conference in Lerici, Italy, has provided impetus in completing a pair of journal articles summarizing the reverberation work during the 1996-1998 Rapid Response Exercises and follow-on JRP's with NURC. A poster presentation was prepared for the conference, and two papers on the measurement and modeling methodology are being prepared for October.

RESULTS

This section illustrates a few examples from the past year's activities.

Reverberation Modeling Workshop

The OGOPOGO and NOGRP models were extended and applied to the 3-D problems in the flat environment [Ellis, 2007] from the Reverberation Modeling Workshop. Figure 1 shows a comparison of the monostatic and bistatic predictions in 100 m isospeed water over a homogeneous fluid halfspace, with Lambert scattering. Note that when the time scales are aligned so that 0 time corresponds to the instant of the pulse, the bistatic prediction soon coincides with the monostatic prediction. The effect of receiver depth is almost insignificant, except near the boundaries. The apparent frequency dependence is not an intrinsic feature of the reverberation; it is simply a propagation effect due to the Thorp volume absorption in the water column. The OGOPOGO model includes the effects of time dispersion using group velocities, so the main blast at 6.7 s is spread in time, rather than having all arrivals arrive at the same time.

Figure 2 shows a comparison by Ainslie [private communication] of reverberation predictions from several models for Problem 11 (isospeed water). Beyond a few seconds there is excellent agreement between the normal mode (NOGRP and CSNAP), ray (SAFFIRE), and energy flux (FLUX) models. For reasons yet not determined, the CSNAP model slightly underpredicts the reverberation. Ainslie considered the NOGRP model to be the most accurate normal mode model. At times less than about 2 seconds, the propagation paths steeper than the critical angle contribute more to the reverberation, so energy flux or ray-based models are more realistic. More detailed analysis is being developed for a journal paper.

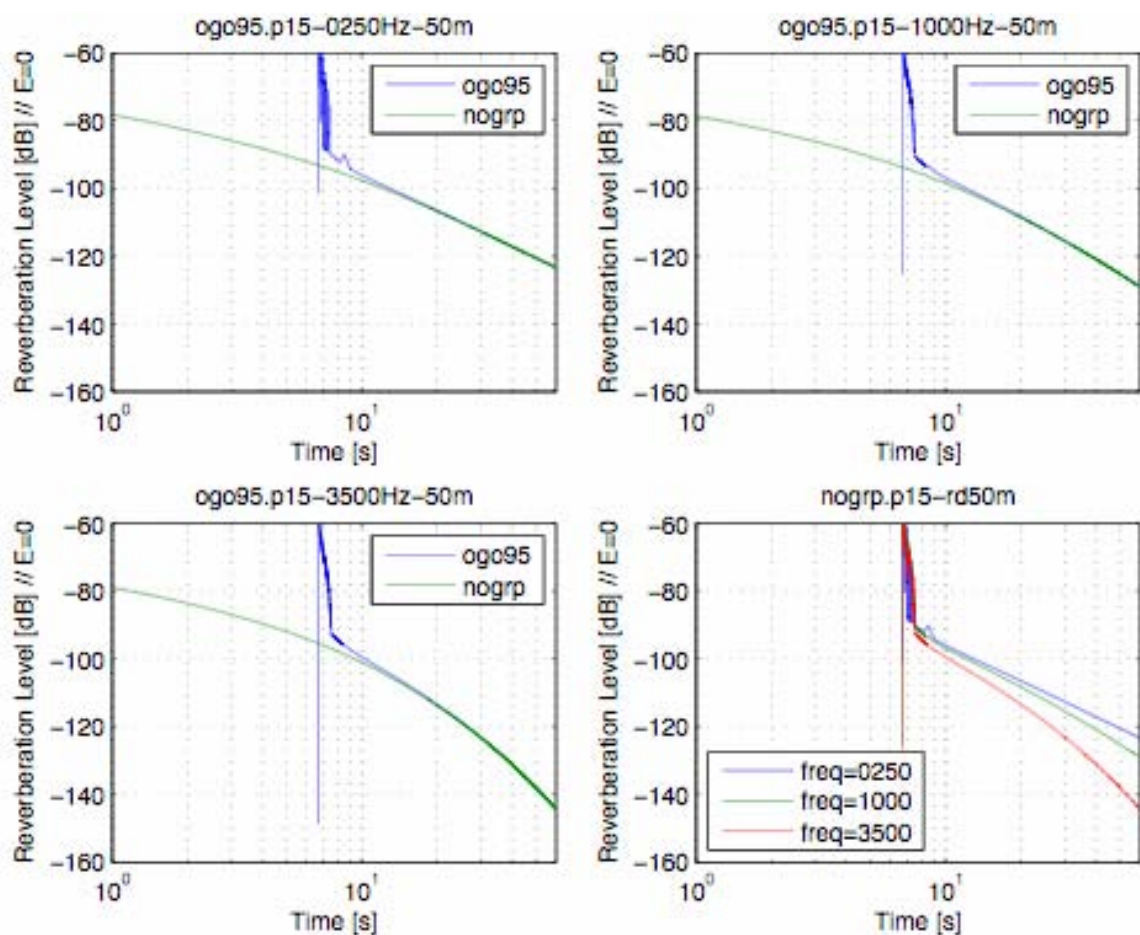


Figure 1. Comparison of monostatic (NOGRP) and bistatic (OGOPOGO) predictions for Workshop problems 11 and 15 at 3 frequencies. The apparent frequency dependence in this problem is almost entirely due to the volume absorption in the water column.

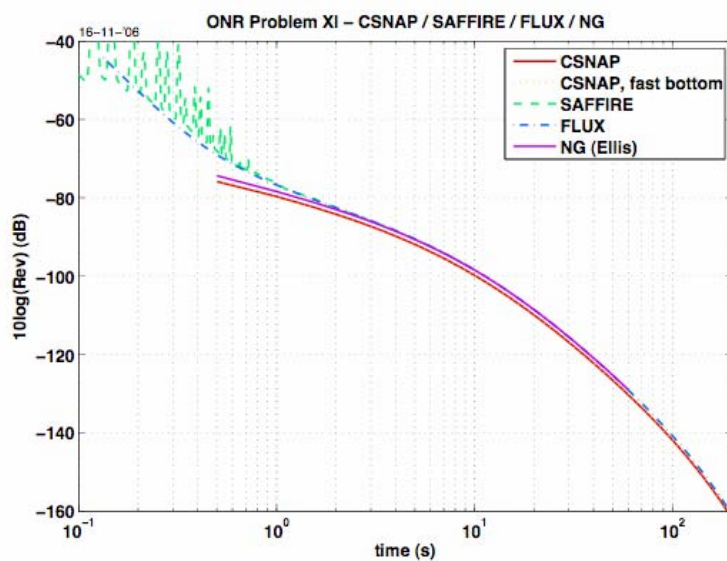


Figure 2. Comparison of several predictions of reverberation for Workshop Problem 11.

Effect of time spreading (modal group velocities)

A feature of the OGOPOGO/NOGRP model is the use of group velocities to simulate the time spreading of the various propagation paths. The effect of the group velocity correction is normally quite small for reverberation since there is an averaging over range. However, if there is a strong scattering feature, such as +20dB enhanced scattering at 28 seconds shown in Figure 3, the reverberation is spread out in time and the peak is reduced. This time spreading effect will have a greater effect on target echo modeling.

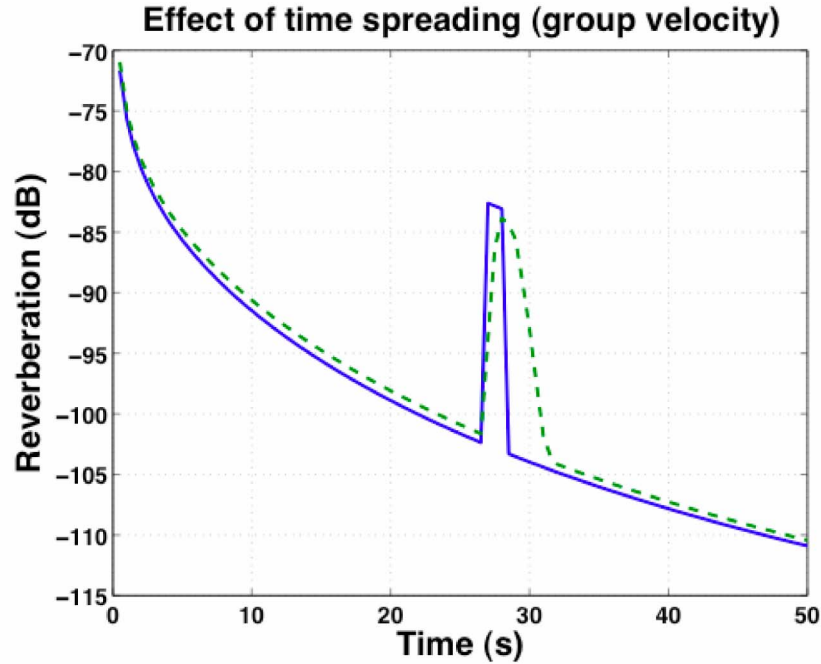


Figure 3. *Effect of time spreading on reverberation. The solid line is for all paths (modes) having the same travel time; the dashed line includes the effects of mode group velocity.*

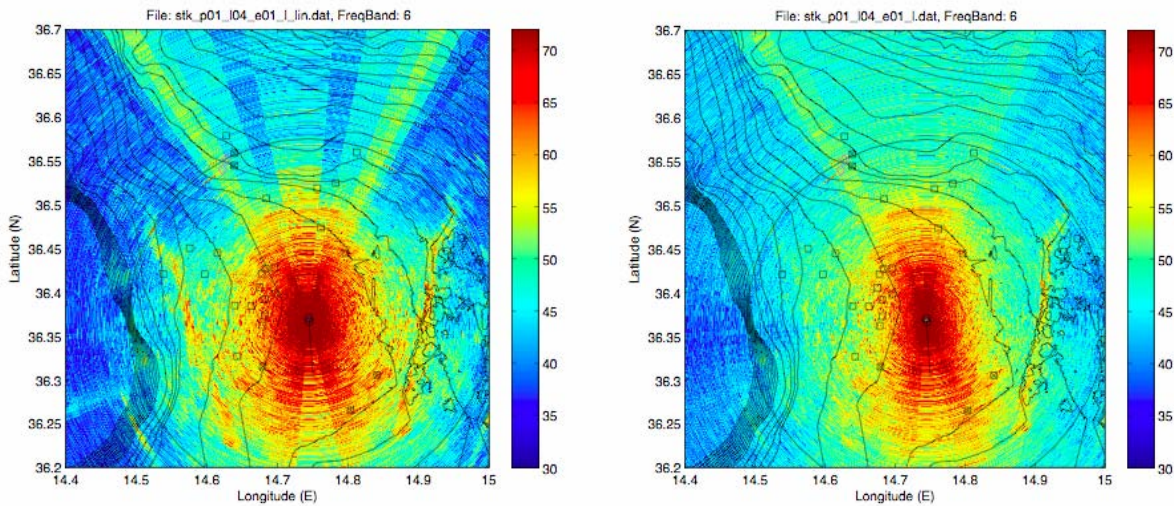


Figure 4. *Comparison of linear and triplet beam forming for the same event.*

Cardioid vs linear beamforming

Figure 4 illustrates the differences between linear and cardioid beamforming. The example is from the NURC cardioid array during the Boundary 2004 experiment on the Malta plateau at 1400 Hz. A Matlab display was developed during the Clutter '07 cruise to easily incorporate the data, contour plots, and clutter features.

IMPACT/APPLICATIONS

From an operational perspective, clutter is viewed as one of the most important problems facing active sonar in shallow water. The long-term objective of this work is to better understand and model reverberation and clutter in shallow water environments, and to develop techniques for Rapid Environmental Assessment (REA) [Sellschopp, 2000; Whitehouse et al., 2004] and environmentally adaptive sonar. Parts of the research have been spun off into a DRDC TIAPS (Towed Integrated Active-Passive Sonar) Technology Demonstrator which has been evaluated in ASW exercises against submarine targets. The work on clutter is related to the DRDC effort in auralization and co-operative work with TTCP and other ONR efforts.

If the target echo model can be validated, this could be a useful method for estimating the target strength of clutter features – and even submarines – in multipath shallow water environments.

RELATED PROJECTS

This project contributes to the US/Canada/NURC Joint Research Project “Characterizing and Reducing Clutter in Broadband Active Sonar,” which receives substantial funding from ONR. This ONR project also contributes to the DRDC Atlantic research program:

http://www.atlantic.drdc-rddc.gc.ca/researchtech/researchareas_e.shtml, in particular, Underwater Sensing and Countermeasures, http://www.atlantic.drdc-rddc.gc.ca/researchtech/underwater-intro_e.shtml.

As well, the personal interaction on this project facilitates additional collaborations between scientists in the various research laboratories.

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