Measurements and Analysis of Reverberation, Target Echo, and Clutter: FY10 Annual Report for ONR

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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 Principal Investigator (PI) to spend approximately three months each year at ARL/PSU. The collaboration leverages programs in Canada, US, and joint research projects 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.

APPROACH

The PI spends three months per year at ARL/PSU, conducting joint research primarily with Drs. John Preston and Charles Holland. 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 conference proceedings and 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 present JRP “Characterizing and Reducing Clutter for Broadband Active Sonar” is essentially complete. A new JRP “Modeling and Stimulation for ASW Active Sonar Trainers” for years 2011–2013 is just starting up, with the PI as the overall Point of Contact.

Over the past few years, the ONR Reverberation Modeling Workshops [PT07, TP08, PT09] have been a

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focus for collaboration. The PI extended and exercised two of his models on a number of problems [Ell08], and collaborated with Preston in developing a Matlab-based model [PE08]. The model is also being validated against more computationally-intensive physics-based models developed by other researchers. Other collaborations with Holland and Ainslie led to presentations at a Special Session of the Acoustical Society of America in November 2007 [EH07, EAH07]. A paper with Holland has been published [HE09], and the paper with Ainslie is in progress. Sub-bottom scattering from the collaboration with Holland [HE09] is now an option in the NOGRP model. The PI was a member of the problem definition committee for the second Reverberation Modeling Workshop held in May 2008.

Recent work has focused on range-dependent reverberation modeing and target echo calculations, both of which are important for developing a “Clutter Model”.

WORK COMPLETED

The ONR Reverberation Modeling Workshops have stimulated further work along the same lines. One such activity was the 2010 Symposium on Validation of Sonar Performance Assessment Tools, sponsored by the UK Institute of Acoustics in memory of David Weston. One of the “Weston Symposium” problems extended the ONR problems to the full sonar scenario, including matched filter processing, background noise, and signal-to-noise ratio. The main organizer was M. Ainslie of TNO in the Netherlands, and the PI provided advice on the problem definitions, which are now being published formally [ZAS10].

During the past year the PI worked on the target echo problem from the 2008 ONR Reverberation Modeling Workshop and the 2010 Weston Symposium. While multipath time spreading is not very important for diffuse reverberation, it can have have a significant effect for feature scattering and target echo [Ell95, EDT97]. A presentation was made at the October 2009 meeting of the Acoustical Society of America [Ell09], and at the Weston Symposium [Ell10b]. An example is shown in the “Results” section below.

The ONR Workshops uncovered differences between model predictions at short times; e.g., ranges less than about 10 water depths, where the fathometer returns and steep-angle reverberation are important. A problem that generated a great deal of discussion was Workshop Problem VI, for the rough bottom with the summer sound speed profile. The PI’s normal-mode results were extended to short times and submitted to the organizers for comparison with other mode models, and ray-model predictions. They were included in a presentation at the October 2009 meeting of the Acoustical Society of America [THYR09].

It is difficult to properly include the short range effects in a normal mode model, so, to investigate the short-time reverberation, a refinement of a 1986 straight-line ray trace model [EF87] was developed and implemented. This also required a careful look at the pulse definition for the Reverberation Modeling Workshop. The results were submitted to the ONR Workshop organizers, and presented at the Weston Symposium [Ell10a].

As part of the model development for model-data comparisons, the fast shallow-water reverberation model [Ell95, Ell08] based on normal modes has been extended to a bistatic, range-dependent clutter model that includes target echo and feature scattering [EPHY08, KE10, EP10]. The formulation based on adiabatic modes had been developed earlier [EPHY08] and calculations were done using Matlab for a flat bottom environment. In 2010 the model was converted to Fortran 95, and extended to handle range-dependent bathymetry and scattering. Like the reverberation model, it is computationally efficient and includes the 3-D effects of towed array beam patterns in order to facilitate comparison with experimental measurements. A short paper will appear in Canadian Acoustics [EP10]. Some results are illustrated in the “Results” section below.

A very useful feature of the clutter model is that it is a subroutine, rather than a standalone program. This facilitates its inclusion in other applications. Work is progressing to include it in the DRDC System Test Bed (a version of which goes to sea with the Canadian Forces); a standalone version with Java GUI and public domain databases is already running on a Windows system [BKTE10]. Further model improvements will occur in the next year, applying it to other problems from the ONR Workshops and Weston Symposiums, as well as comparisons with towed array data, particularly from the Clutter ’07 and Clutter ’09 trials.

RESULTS

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

Time spreading of scattering features and target echo

Figure 1 illustrates the reverberation from a flat bottom with Lambert scattering. The environment is as described in Problem IX of the Reverberation Workshop. The problem was modified by increasing the scattering strength by 10 dB from -27 dB to -17 dB, for a 100 m annulus between 20.0 to 20.1 km. If the travel time for all the paths is assumed to be the same, as is typically done in many formulations, the reverberation would jump by 10 dB for 0.133 s. The blue curve shows the computations done using a normal mode reverberation model at 250 Hz. If, however, the different multipaths take different travel times, then the scattering from the feature is spread in time; the green curve shows the impulse response using the modal group velocities, and the red curve shows the impulse convolved with a uniform pulse of duration 0.08 s. (Note that the red curve overlies much of the green curve.) Outside the scattering region, the curves with and without the group velocity correction differ by about 0.5 dB. This is because the constant group velocity was chosen to be 1500 m/s, but the actual group velocities are all less than this; thus, the scattering at a given instant of time is coming from shorter ranges where the propagation loss is less, and so gives slightly higher reverberation. The small difference is generally not important, so the extra computation to handle the different modal travel times is not usually needed for reverberation calculations.

However, the situation is much different for the target echo, as illustrated in Fig. 2. If all the multipaths arrived at the same time, then the echo would have the same shape as the pulse, and the peak would lie on the dark green curve. The echo-to-reverberation ratio for the example shown would be about -3 dB. However, with different multipath travel times the echo is stretched out in time, and the amplitude is reduced. The light green dots in the figure correspond to the different arrival times of the mode pairs, and the red curve is the Hann-shaped pulse convolved with the impulse responses. In this case the peak response is reduced by about 6 dB, so the peak echo to reverberation ratio now about -9 dB. This can be quite important for detection predictions based on signal excess.

These results shown are for normal modes, but similar results can be obtained with other models that include time spreading (such as Holland’s energy flux approach).

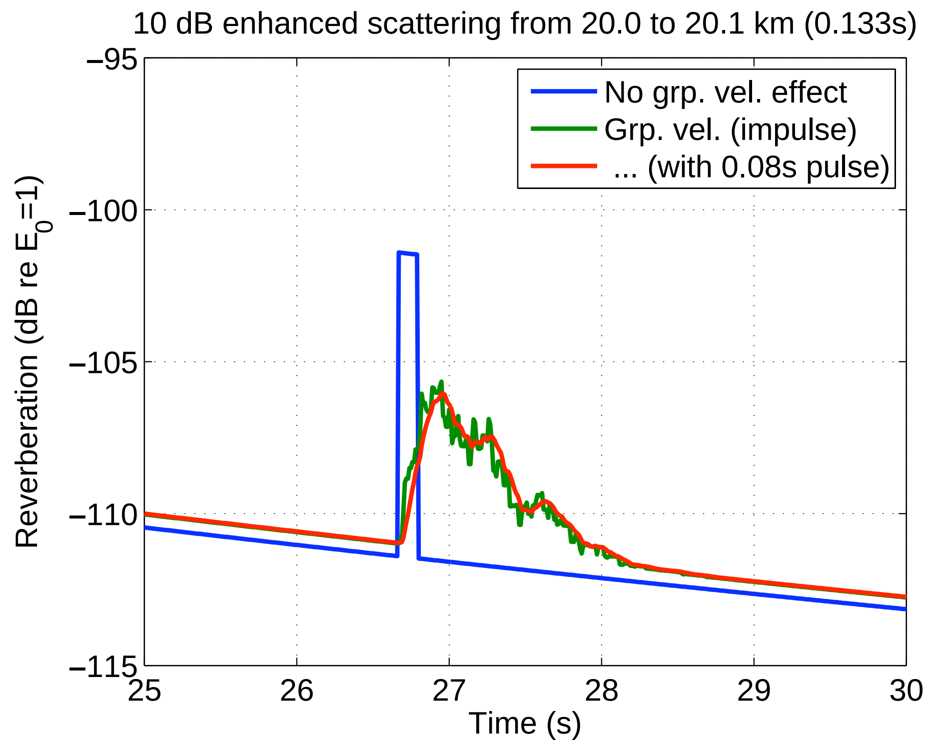

Figure 1: Reverberation structure at 250 Hz from a scattering annulus enhanced by 10 dB for 100 m extent in range.

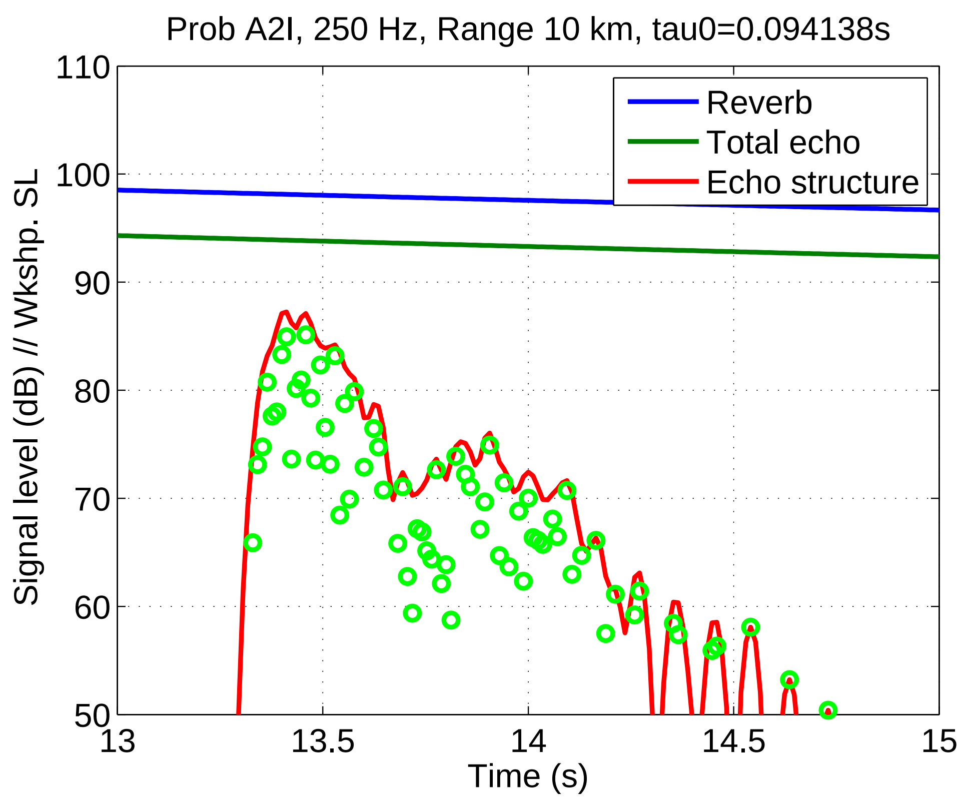

Figure 2: Echo time structure for a point target at range 10 km.

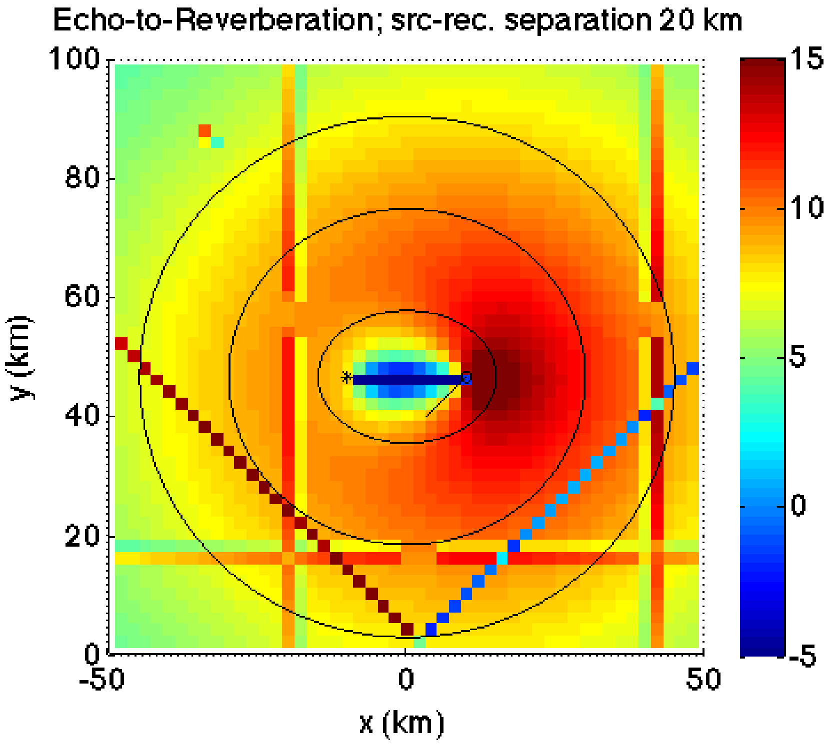

Figure 3: Echo-to-reverberation ratio in 100 by 100 km area using ideal beam patterns. The source is indicated by a *, and the receiver by a ○ with heading 225° indicated by the short line; the time ellipses indicate 20, 40 and 60 s.

Range dependent clutter model

The formulation for a range-dependent clutter model based on adiabatic modes had been developed earlier [EPHY08] and calculations done for a flat bottom. In 2010 the initial version of the bistatic range-dependent version became operational. Two calculations are illustrated in Figs. 3 and 4; these calculations will appear in a short paper in Canadian Acoustics [EP10].

Figure 3 shows the signal excess (target echo-to-reverberation level in dB) on a grid generalized from Fig. 2 in [EPHY08]. The area is 100 km square with coordinates between $(x,y) =$ (-50,0) km and $(x,y) =$ (50,100) km. A 50×50 grid is used for the calculations, so the center of the grid points range from approximately (-49,1) km to (49,99) km with increments of 2 km in each direction. The water depth is 100 m, except for two ridges in the y-direction rising to 60 m, and another ridge rising to 70 m in the x-direction; both have gaps near the middle. There is a single seamount of height 50 m near $(x,y) =$ (-40,85) km. The bottom has Lambert scattering with a strength of -27 dB, except for a +10 dB enhancement along the line (2,2) km to (50,50) km. Similarly the target (at depth 10 m) has echo strength of 8 dB, except for a 7 dB enhancement along the line (-48,52) km to (2,2) km. The source is at (-10,45) km at depth 30 m, and the receiver at (10,45) km at depth 50 m.

The basic environment is similar to the ONR 3D problems. It has isospeed water of 1500 m/s over a sand bottom half space of density 2.0 relative to seawater, sound speed 1750 m/s and attenuation of 0.5 dB/wavelength; the volume absorption in the water is a version of Thorp's formula. The source is omni-directional with unit energy (10 dB source level for a duration of 0.1 s), operating at a frequency of 250 Hz. The towed array was chosen to give a horizontal beam width of 3.6°; 39 omnidirectional

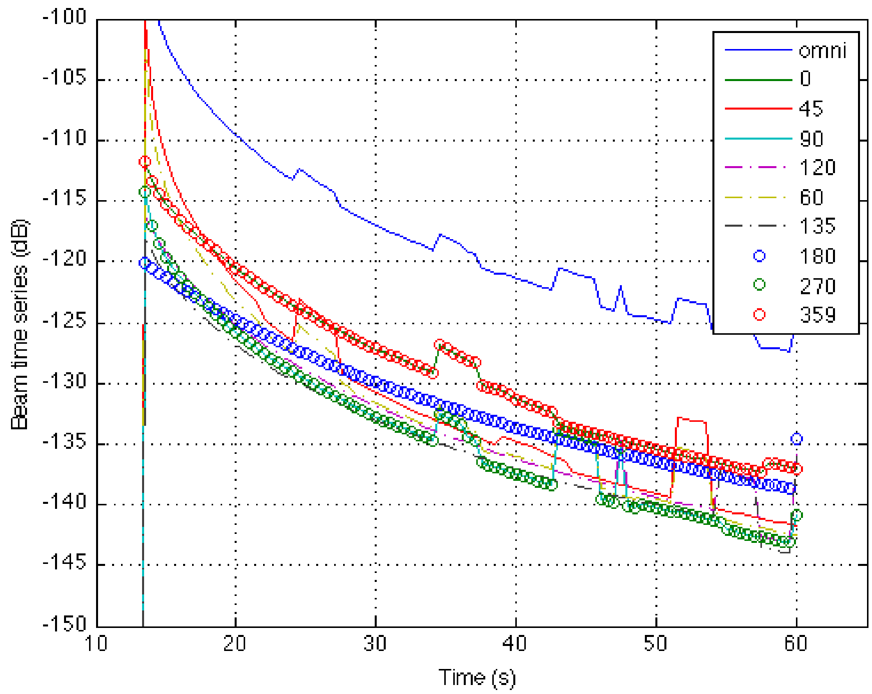

Figure 4: Towed array reverberation beam time series corresponding to Fig. 3.

elements at spacing of 2.5 m with Hann weights were used for the beam time series. The CPU time on a 2 GHz computer was only 1.5 s, with modes (usually 16) being calculated at each of the 2500 grid points.

For the grid calculation, the beam pattern corresponds to an ideal one sided broadside beam steered at all azimuths; this gives a nice picture of the physical scattering. In Fig. 3 the receiver sees high reverberation (low echo-to-reverberation ratio) in the direction of the source (west, W); similarly along the high scattering line to the SE. The higher echo strength along the line to the SW shows up clearly too. Along the three ridges, the echo to reverberation ratio first drops (due to the higher reverberation on the up slope), then increases on the down slope. Beyond the ridges one would expect some shading due to mode cutoff, but none is observed; perhaps the reverberation and echo are affected similarly. The single point to the NW affects the echo-to-reverberation ratio in the adjacent cells. The ellipses correspond to 20 s, 40 s and 60 s after the short pulse, and are useful for identifying features in the beam time series shown in Fig. 4.

For the beam time series, the actual conical beam pattern with left-right ambiguity is used, so it can be directly compared with measured towed array data. However, interpretation is not as straightforward as for Fig. 3. Figure 4 shows time series corresponding to Fig. 3, and a selection of beam steering angles relative to the towed array heading of 225°. The predictions generally seem to make sense. The reverberation on the omni receiver is 10–15 dB above the beam predictions; at short times the reverberation on the 45° and 60° beams is higher since they look in the direction of the source (note the beams have left-right symmetry); the 45° beam also seems to be picking up backscatter from the ridges to the W (at about 25 s), the ridge to the S (at about 40 s), and from the strong scattering line (to the south at 53 s); the 0° and 359° beams are essentially identical; the 90° and 270° beams should be identical, and have the lowest reverberation, except in the region of features; at long ranges the endfire beams (0° and 180°) should have the highest reverberation, and in a uniform environment approach each other.

The model continues to evolve. Presently the same sound speed profile and bottom loss are used at all locations. The next step will be to generalize it. For production calculations, it makes sense to pre-calculate the modes on the grid, perhaps interpolating them to a finer scale. Then, for other source-receiver geometries and multistatic scenarios, they can be re-used for rapid reverberation and target echo calculations. The model is being incorporated in the DRDC System Test Bed; a stand alone Windows version with a Java interface is already working [BKTE10].

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) and environmentally adaptive sonar. Parts of the earlier 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.

One goal is to be able to use the model with real clutter data from a towed array. One could subtract out the background reverberation, including range-dependent effects and known scattering features, leaving behind the unidentified clutter on a display. These unidentified features would then be investigated by other techniques to try to determine their nature.

TRANSITIONS

The range-dependent reverberation and target echo model is being implemented as the Clutter Model on the DRDC System Test Bed (a prototype sonar processing system), a version of which is the Pleiades System used in some Canadian Forces exercises. Research contracts to incorporate the reverberation and target echo were let to General Dynamics of Canada Limited in 2009, and a follow-on contract to Brooke Numerical Services in 2010. A standalone version with public domain databases and a Java GUI is presently operational [BKTE10] under a Windows operating system, and integration with the System Test Bed is anticipated early in 2011.

The David Weston Sonar Performance Assessment Symposium was held in Cambridge, UK, 7–9 April 2010. It had number of scenarios based on the ONR Reverberation Modeling Workshop problems, extended to the complete sonar problem. The driving force behind the sonar modeling is the Low Frequency Active Sonar program of TNO and the Royal Netherlands Navy.

RELATED PROJECTS

This project has contributed to the US/Canada/NURC Joint Research Project "Characterizing and Reducing Clutter in Broadband Active Sonar" which received substantial funding from ONR. A new proposal "Modelling and Stimulation for ASW Active Sonar Trainers" has been approved for the 2011–2013 Scientific Program of Work at NURC.

This ONR project also contributes to the DRDC Atlantic research program:
http://www.atlantic.drdc-rddc.gc.ca/researchtech/science_sections_eng.html,
in particular, Underwater Sensing,
http://www.atlantic.drdc-rddc.gc.ca/researchtech/us_eng.html.

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

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PUBLICATIONS

The following publications were accepted or published during the past year:

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- D. D. Ellis and J. R. Preston. Extracting bottom information from towed-array reverberation data. Part II: Extraction procedure and modelling methodology. *J. Mar. Syst.*, 78:S372–S381, 2009. [published, refereed]
- T. Kwan and D. D. Ellis. Reverberation calculations over sloping ocean bottoms. DRDC Atlantic Technical Memorandum TM 2009-192, DRDC Atlantic, Dartmouth, NS, Canada, June 2010. 74 pp. [in press]
- G. H. Brooke, S. J. Kilistoff, D. J. Thomson, and D. D. Ellis. Performance prediction via the java Acoustic Model Interface. *Canadian Acoustics*, October 2010. [in press]
- D. D. Ellis and S. P. Pecknold. Range-dependent reverberation and target echo calculations using the DRDC Atlantic Clutter Model. *Canadian Acoustics*, October 2010. [in press]