Modeling and Analysis of Target Echo and Clutter in Range-Dependent Bistatic Environments: FY12 Annual Report for ONR

Dale D. Ellis
DRDC Atlantic
P. O. Box 1012, Dartmouth, NS, Canada B27 3Z7
phone: (902) 426-3100 ext 104   fax: (902) 426-9654   email: daledellis@gmail.com

LONG-TERM GOALS

The long-term goal of this work is to better understand and model reverberation, target echo, 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 two months each year at ARL/PSU. The collaboration leverages programs in Canada and the US, and joint research projects with the NATO Centre for Maritime Research and Experimentation (CMRE) [formerly known as 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 two months per year at ARL/PSU, conducting joint research primarily with Dr. John Preston and Dr. 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 have been Joint Research Projects (JRPs) between CMRE, Canada and several US research laboratories (ARL in particular). The JRP "Characterizing and Reducing Clutter for Broadband Active Sonar" is now complete. A proposed JRP "Modeling and Stimulation for ASW Active Sonar Trainers" for years 2011–2013 was accepted by CMRE, but no resources seem to have been yet allocated. The focus for experiment design and data analysis is now the ONR mid-frequency

reverberation and target echo experiments in the Gulf of Mexico near Panama City, Florida [TH12].

Model development to support experiment design and data interpretation is a major focus of the work. Recent work by the PI has focused on bistatic range-dependent reverberation modeling and target echo calculations. A bistatic range-dependent "Clutter Model" [EP11, EPB12] based on adiabatic normal modes has been developed, and comparisons made with towed array data from the Malta Plateau. The model was recently extended to handle towed arrays with triplet elements, and predictions of reverberation and target echo made [EPB12] in support of the GulfEx12 and TREX13 experiments. Reverberation data from the Malta Plateau have indicated that sub-bottom scattering is important [Hol02], so, in collaboration with Holland, the mode model was initially extended to handle sub-bottom scattering [HE09], and later extended to include sub-bottom range-dependence [HE12].

Over the past few years, the ONR Reverberation Modeling Workshops [PT07, TP08, PT09] have been a 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]. For the Pekeris model with Lambert bottom scattering, extensive comparisons have been made [AEH11] between energy-flux, normal mode, ray-based models, and analytical approaches, and a journal paper has been submitted [AEH13].

The ONR Reverberation Modeling Workshops (RMW) have stimulated further work; e.g., the 2010 Symposium on Validation of Sonar Performance Assessment Tools [Ain10], sponsored by the UK Institute of Acoustics. The "Weston Symposium" extended [ZAS10] the ONR problems to the full sonar scenario, including matched filter processing, background noise, and signal-to-noise ratio. The PI was a member of the problem definition committee for the second Reverberation Modeling Workshop, held in May 2008, and provided advice on several iterations of the Weston Symposium problem definitions. In addition, structured sessions have been organized at the 2011 Underwater Acoustics Measurements Conference (UAM) and the 2012 European Conference on Underwater Acoustics (ECUA). A similar session at the 2013 ECUA is planned.

WORK COMPLETED

This section summarizes some of the work completed in FY2012.

Analysis of reverberation data from the Malta Plateau has indicated that sub-bottom scattering is important. In 2007–08 the normal model was extended to handle sub-bottom scattering [HE09]. In 2010–2011 it was further extended to handle a range-dependent sub-bottom reverberation. In collaboration with Holland it was shown that slowly-varying sub-bottom features could result in discrete target-like returns. A presentation [HE11] was made at the Fall 2011 meeting of the Acoustical Society of America, and a paper submitted, accepted, and published [HE12]. Some details are given in the "Results" section below.

In 2012, the Clutter Model [EP10, EP11] development was extended to handle left-right ambiguity of the Five Octave Research Array (FORA) triplet array, and preliminary calculations made for the upcoming 2013 TREX experiment [EPB12]. Some details are given in the "Results" section below. Comparisons with data from the Malta Plateau were extended to 1750 Hz. In addition, DRDC funded Brooke Numerical Services to enhance the Java GUI interface for a more user-friendly tool [HBTT12].

Additional work was done on the validation of reverberation and target echo models. The comparisons

[AEH11] for the Pekeris model benchmarks were reworked and submitted to the Journal of Computational Acoustics [AEH13]. The details of the near-range fathometer returns, calculated using a ray-path model, were described in a laboratory report [Ell12]. The initial work [Ell11, PE11] on range-dependent RMW and Weston Symposium test cases was extended using the author's model r2d3 [EP12], and Preston's Matlab-ORCA version [PE12]. Additional model-model comparisons were made in collaboration with Ainslie et al. [AZE12].

The PI was co-organizer of a Structured Session on Sonar Performance Modelling and Validation at the 2012 ECUA, and contributed four papers [EP12, EPB12, AZE12, PE12] of which he was principal author of two. A similar Structured Session is planned for the joint UAM/ECUA meeting in 2013.

RESULTS

This section illustrates a few results from the activities mentioned in the previous section. The first example is taken from the 2012 paper at the European Conference on Underwater Acoustics [EPB12]. The second example expands on some material in the journal paper by Holland and Ellis [HE12] on clutter due to non-discrete changes in the environment.

Calculations for GulfEx12 and TREX13 experiments

Reverberation and target echo experiments [TH12] are to be conducted off Panama City, Florida, USA, in 2012 (GulfEx12) and 2013 (TREX13). The receiver is the FORA array [BP03], maintained for ONR by ARL/PSU. It has a triplet section that can be used to form broadside cardioids [Pre07].

For the experiments, the triplet section is to be deployed as a fixed receiver. The 78 elements at 0.2 m spacing (design frequency of 3750 Hz) are Hann-weighted and used to form 79 beams, equally spaced in the sine of the beam steering angle, from forward to aft end fire on each side; the triplets in each element are used to form broadside cardioids on the appropriate side, giving a total of 158 beams.
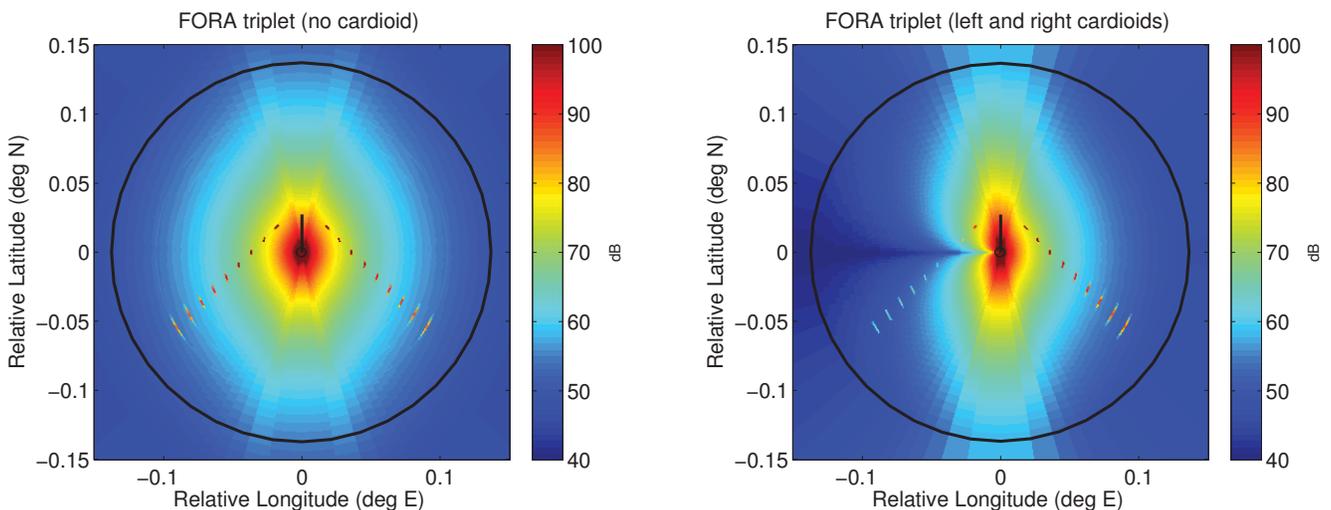

Figure 1: Left: Polar plot of reverberation received on linear array (triplet array without cardioid processing). The black circle indicates 20 s and the black line indicates array heading. Right: Polar plot of target echos and reverberation from right side of array received on triplet array (both left and right beams with cardioid processing).

3

Calculations were made using the Clutter Model [EP10, EP11, EPB12]. The initial calculations were with the forward end fire beam pointing north, in water of 20 m depth, over a flat, uniform, sandy bottom. The water was assumed isovelocity, 1520 m/s. The bottom properties [HOSH10], from previous experiments in the area, use a half-space with sound speed 1680 m/s, density 2040 kg/m^3, and attenuation 0.84 dB/wavelength (or 0.5 dB/m-kHz). Reverberation was assumed due to bottom scattering using Lambert's rule with a -27 dB scattering strength. The source was omnidirectional, operating at 3000 Hz with a source level of 200 dB re 1μPa at 1 m for a duration of 0.1 s. Nine targets (point targets of 15 dB strength) were located in a line eastward of the array at locations $x = [2 : 1 : 10]$ and $y = [2 : -1 : -6]$ km. The ambient noise on each beam was assumed to be 40 dB re 1μPa^2/Hz. (For the calculations here, the reverberation exceeds this value). Predictions of the beam time-series to 25 s were calculated, with the source near the midpoint of the array. The source was assumed to be at a depth of 10 m, the array at a depth of 15 m, and the targets at a depth of 10 m.

Figure 1 (left panel) shows reverberation and echo predictions for FORA processed as a linear array; i.e., with the cardioid turned off. The beam time series are displayed on a polar grid, as described in [EP09]; essentially, the beams are mapped into azimuth, and the time mapped into range. In the plots here, the 20 s point is marked by a black circle, and the beam time series are displayed as constant beyond 25 s. The targets appear on both the left-looking and right-looking beams. The right panel simulates the effect of the triplet array, with predictions for the full 360° set of beams, but assuming the reverberation is only coming from area to the right of the array. It illustrates the effect of the cardioid in suppressing signals from the ambiguous beams.

To make the predictions more realistic, bathymetry was included in the calculations. Bathymetry was taken from GEBCO_08 [GEB10], which has a grid spacing of one-half minute in latitude and longitude (about 0.926 km north-south or at the equator). The left panel of Fig. 2 shows the bathymetry in the region of the experiment, with contours at 10 m intervals calculated using Matlab. To ensure that there were modes at each grid point, the minimum water depth (including land areas) was set at 5 m. For clutter objects there were 4 targets on broadside at 1, 2, 5 and 10 km (modeled as 10 dB point objects at 10 m depth), and 9 targets on a SE line at 1 km spacing in both x and y; i.e., $x = [1 : 1 : 9]$ km, $y = [1 : -1 : -7]$ km; the target strengths were 15 dB with depths selected to alternate between 1 and 10 m. (The 1 m depth was chosen to get some idea of the effect of echos from the hull of a ship). Figure 2 (right) shows a polar plot of the predicted beam time series. Most of the target echoes are visible on the right-looking beams. On the left-looking beams, the echos from the targets at broadside are completely eliminated by the null on the back side of the cardioid; a couple of the echoes from the long-range targets have leaked through to the ambiguous beam and are faintly visible.

The line plot in Fig. 3 shows the time series for beam 50 (looking SE at the targets). All echos appear well above the reverberation level. At the longest range 12.7 km (16.7 s) the echo level of the target at 1.0 m depth is about 10 dB lower than for the target at 10.0 m depth.

Target-like clutter due to a slowly-varying environment

It is well understood that discrete objects can lead to clutter. A somewhat counter-intuitive result is shown: that discrete target-like returns can occur from slowly varying seabed structures. The range dependence of the seabed can be weak and smooth – due to changes in layer thicknesses, sound speed, or both. Several examples were given in a journal paper by Holland and Ellis [HE12], mostly using the energy-flux formulation. The phenomenon can be understood using normal modes. Some additional details are presented here.
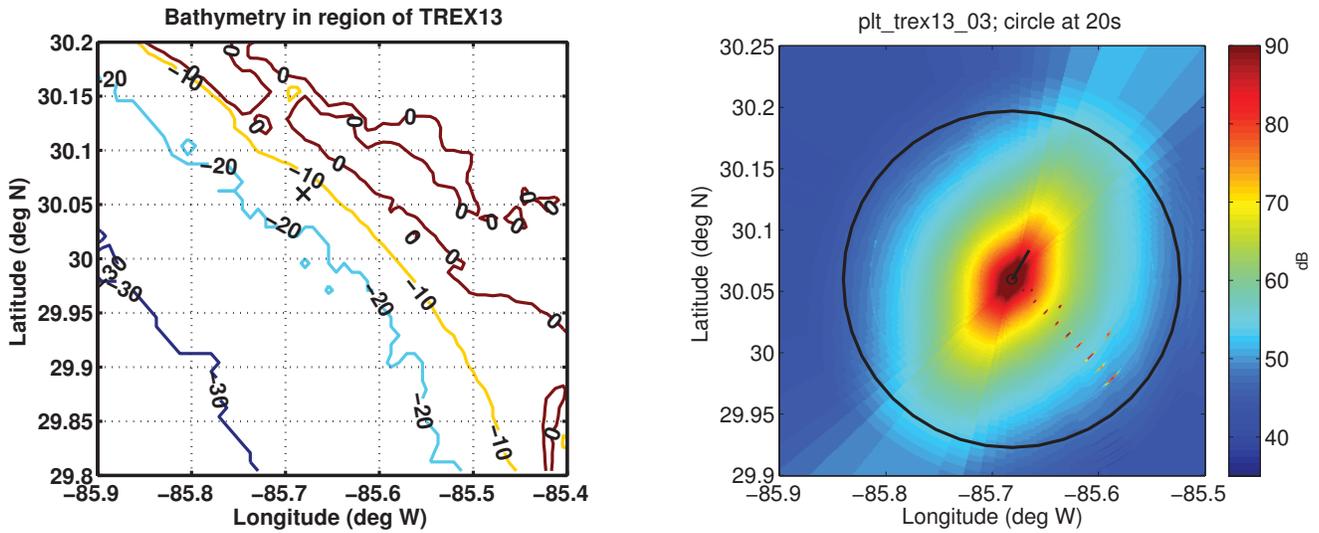
Figure 2: *Left: Bathymetry (contours at 0, 10, 20 and 30 m, with depth increasing to the SW) in the region of Panama City. The array location near the centre is marked by ×. Right: Polar plot of reverberation and target echos using range-dependent bathymetry and cardioid beamforming. Most of the target echoes are visible on the right-looking beams. On the left-looking beams, the echos from the targets at broadside are completely eliminated by the null on the back side of the cardioid; a couple of the echoes from the long-range targets have leaked through to the ambiguous beam and are faintly visible.*
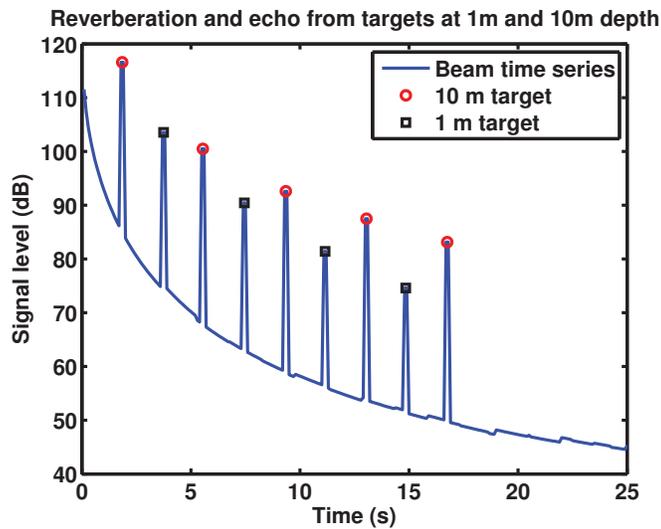

Figure 3: *Signal level for towed array beam looking in direction of the targets (at 1 and 10 m depths, alternating).*
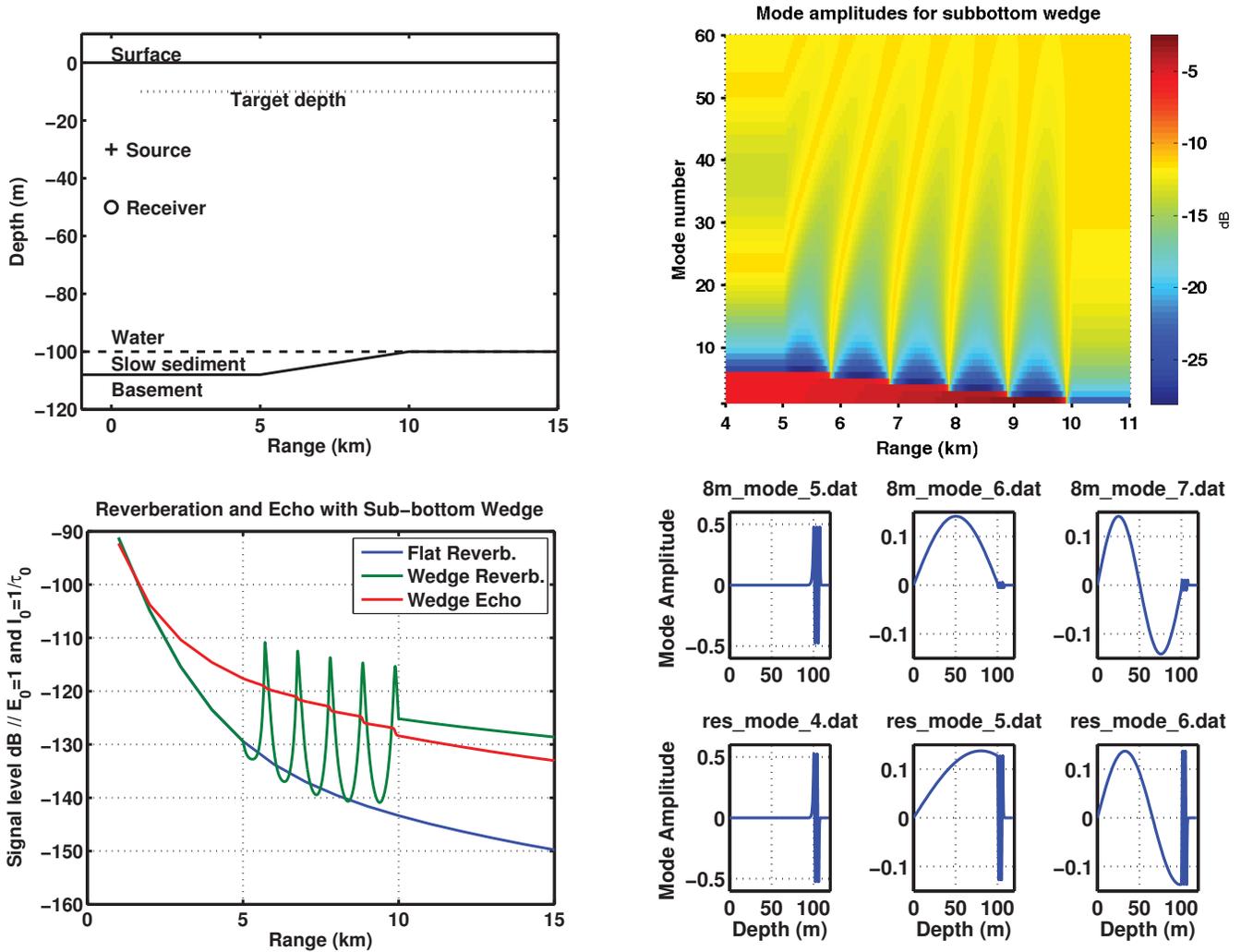
5

Figure 4: Upper left: The environment with a thin, slow-speed, sub-bottom wedge between 5 and 10 km; Upper right: Mode amplitudes (in dB) in the sub-bottom wedge; Lower left: Reverberation and echo calculations; note the sharp target-like peaks in the reverberation for the wedge case, compared to the flat-bottom case; Lower right: Mode functions (5, 6, 7) for non-resonant (8 m thick layer) and modes 4, 5, and 6 for resonant (6.74 m thick layer) situations.

Figure 4 illustrates some calculations using adiabatic normal modes. The upper left panel shows the environment with a slow-speed sub-bottom wedge, decreasing in depth from 8 m to 0 m between 5 and 10 km. The water sound speed is 1512 m/s, the basement sound speed is 1660 m/s, and the slow sediment layer has a sound speed of 1470 m/s. The scattering occurs at the basement interface. The lower left panel shows the reverberation and target echo as a function of time at 2 kHz, as calculated by the adiabatic normal mode model. This is quite similar to the energy-flux calculations given in the journal paper [HE12]. Note the 5 sharp reverberation peaks, which are due to a resonant effect whereby the energy in the water is transmitted into the soft bottom layer striking the basement interface. The upper right panel shows the mode amplitudes in the sediment as a function of range at 2 kHz. Initially there are 5 modes trapped in the 8 m of sediment. They have high amplitude relative to the waterborne modes, since all the energy is trapped in the layer, rather than spread out over the entire water column. As the sediment thickness decreases with range, they disappear one by one. It is tempting to think of these high-amplitude sediment modes being cut off, spilling their energy into the water column, and sending high intensity reverberation back to the receiver. However, this is not the case, since these modes are not excited by the source in the water column. Rather, the same conditions that give rise to the cutoff of each sediment mode allow energy from the water column to be readily transmitted into the sediment, and back into the water column after scattering from the sediment-basement interface.

The lower right panel compares modes in the non-resonant (8 m layer thickness) and resonant conditions (6.74 m layer thickness). For the non-resonant condition the phase of the sinusoidal mode function in the water is approximately a multiple of π, while for the resonant condition the phase is approximately an odd multiple of $\pi/2$. Note the higher amplitude for the layer modes on the left $\sim\sqrt{2/D}$, where D is the layer thickness, compared to the water-borne modes with amplitude $\sim\sqrt{2/H}$, where H is the water depth. This condition persists to high mode numbers, where even around mode 20 the bottom amplitude is relatively strong. Notice also the strong almost-vertical bands in Fig. 4 (upper right). Recall [Ell95] that the mode amplitude for the scattering is the peak amplitude of the sinusoid, not the actual value of the mode function at the interface since it includes the phase.

The effects of a low-speed resonant layer have been noticed before in regard to propagation. Hastrup [Has80] pointed out that the nulls in the reflection correspond to the condition of trapped modes in the low velocity layer and predicted that these nulls might be seen experimentally as high transmission loss at the null condition. Rubano [Rub80] was the first to see the effect experimentally, and it was later re-examined by Siderius and Hermand [SH99]. In the lower right we see that the target echo has small but abrupt changes in the regions of the high scattering, due to the high losses near these regions.

Normally one would associate high transmission loss with low reverberation. Here it is interesting that, although the high loss is present at only the range of interest, the scattering is also enhanced, so the reverberation exhibits a clutter-like peak.

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. The work on clutter is related to the DRDC effort in auralization and co-operative work with TTCP and other ONR efforts.

One goal is to be able to use the model with real clutter data from a towed array. 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 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.

The sub-bottom clutter mechanism may be a viable hypothesis for areas in which seabed clutter has been observed, but no discrete features, buried or proud, could be found. By using a broadband source, the time-frequency evolution of this clutter could be a useful way to discriminate against other kinds of clutter; e.g., that are due to discrete objects.

TRANSITIONS

Small research contracts for the Clutter Model implementation were let in 2009, 2010, 2011, and 2012. A standalone version with public domain databases and a Java GUI was developed by Brooke Numerical Systems [BKTE10] in 2010. It has been improved in 2012 [HBTT12], and the hope is to be able to fully integrate the Clutter Model for comparison with towed array data.

The newly approved DRDC Technical Demonstration Project AMASE (Advancing Multistatic Active Sonar Employment) will make use of many of the techniques developed under this collaborative project.

The 2010 David Weston Sonar Performance Assessment Symposium held in Cambridge, UK, 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

In the past 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 "Modeling and Stimulation for ASW Active Sonar Trainers" has been approved for the 2011–2013 Scientific Program of Work at CMRE, but there has been no activity on it.

Work is being done in preparation for the Panama City reverberation experiments [TH12]; DRDC Atlantic is planning to participate, along with their research vessel CFAV Quest.

This ONR project also contributes to the DRDC Atlantic research program:
    http://www.drdc-rddc.gc.ca/drdc/en/centres/drdc-atlantic-rddc-atlantique/ ...
research-technology-reserche-technologie/
in particular, Underwater Sensing,
    http://www.drdc-rddc.gc.ca/drdc/en/centres/drdc-atlantic-rddc-atlantique/ ...
research-technology-reserche-technologie/underwater-sensing-detection-sous-marine.

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

REFERENCES

[AEH11] Michael A. Ainslie, Dale D. Ellis, and Chris H. Harrison. Towards benchmarks of low frequency reverberation level in a Pekeris waveguide: Insight from analytical solutions. *J. Acoust. Soc. Am.*, 129(5, Pt. 2 of 2):2631, 2011. Abstract 4pUW10. Presented by M. Ainslie at 161st Meeting of the Acoustical Society of America, Seattle, WA, USA, 23–27 May 2011.

[AEH13] Michael A. Ainslie, Dale D. Ellis, and Chris H. Harrison. Low frequency bottom reverberation in a Pekeris waveguide with Lambert's rule. *J. Comp. Acoust.*, 2013. Submitted January 2012.

[Ain10] Michael A. Ainslie. Validation of Sonar Performance Assessment Tools: A workshop held in memory of David E. Weston, 7–9 April 2010. *Proc. Institute of Acoustics*, 32, Pt. 2:1–185, 2010.

[AZE12] Michael A. Ainslie, Mario Zampolli, and Dale D. Ellis. The Weston Memorial workshop: Progress to date on the low frequency active sonar scenarios. In *Proceedings of the 11th European Conference on Underwater Acoustics*, pages 1816–1819, 2012. Conference held in Edinburgh, Scotland, UK, 2–6 July 2012; file p345.pdf on CD.

[BKTE10] G. H. Brooke, S. J. Kilistoff, D. J. Thomson, and D. D. Ellis. Performance prediction via the java Acoustic Model Interface. *Canadian Acoustics*, 38(3):64–65, September 2010.

[BP03] K. M. Becker and J. R. Preston. The ONR Five Octave Research Array (FORA) at Penn State. In *Oceans 2003 Proceedings*, pages 2607–2610. Oceanic Engineering Society, IEEE, September 2003. Meeting held at San Diego, CA.

[Ell95] Dale D. Ellis. A shallow-water normal-mode reverberation model. *J. Acoust. Soc. Am.*, 97:2804–2814, 1995.

[Ell08] Dale D. Ellis. Normal-mode models OGOPOGO and NOGRP applied to the 2006 ONR Reverberation Modeling Workshop problems. Technical Memorandum TM 2006-289, DRDC Atlantic, Dartmouth, NS, Canada, June 2008.

[Ell11] Dale D. Ellis. Solutions to range-dependent reverberation and sonar workshop problems using an adiabatic normal mode model. In Papadakis and Bjørnø [PB11], pages 485–490. Contributed paper in Structured Session "Active Sonar Performance Modeling, Validation and Simulation".

[Ell12] Dale D. Ellis. Calculations of reverberation and fathometer returns at short times using a straight-line ray-path model. Technical Memorandum TM 2011-323, DRDC Atlantic, Dartmouth, NS, Canada, February 2012. 40 pp.

[EP09] Dale D. Ellis and John R. Preston. Extracting bottom information from towed-array reverberation data. Part II: Extraction procedure and modelling methodology. *J. Mar. Syst.*, 78:S372–S381, 2009.

[EP10] Dale D. Ellis and Sean P. Pecknold. Range-dependent reverberation and target echo calculations using the DRDC Atlantic Clutter Model. *Canadian Acoustics*, 38(3):72–73, September 2010.

[EP11]   Dale D. Ellis and John R. Preston. DRDC Clutter Model: Range-dependent predictions compared with towed array reverberation and clutter data from the Malta Plateau. In Papadakis and Bjørnø [PB11], pages 657–664. Invited paper in Structured Session "Temporal and Spatial Variability of Clutter, Reverberation and Propagation".

[EP12]   Dale D. Ellis and Sean P. Pecknold. Reverberation and target echo calculations for range-dependent sonar problems. In *Proceedings of the 11th European Conference on Underwater Acoustics*, pages 1543–1550, 2012. Conference held in Edinburgh, Scotland, UK, 2–6 July 2012; file p287.pdf on CD.

[EPB12]   Dale D. Ellis, John R. Preston, and Gary H. Brooke. Progress on the DRDC Clutter Model. In *Proceedings of the 11th European Conference on Underwater Acoustics*, pages 1490–1497, 2012. Conference held in Edinburgh, Scotland, UK, 2–6 July 2012; file p274.pdf on CD.

[GEB10]   General Bathymetric Chart of the Oceans (GEBCO): The GEBCO_08 Grid. Technical report, Intergovernmental Oceanographic Commission (IOC) (of UNESCO) and the International Hydrographic Organization (IHO), British Oceanographic Data Centre, UK, 2010. Last accessed: 2012 March 15 at http://www.gebco.net/data_and_products/\discretionary{-}{}{}gridded_bathymetry_data/\discretionary{-}{}{}documents/gebco_08.pdf; data file is gebco_08.nc, version 20100927.

[Has80]   Ole F. Hastrup. Some bottom-reflection loss anomalies near grazing and their effect on propagation in shallow water. In W. A. Kuperman and F. B. Jensen, editors, *Bottom-Interacting Ocean Acoustics*, pages 135–152. Plenum Press, New York, NY, 1980.

[HBTT12] Craig Hamm, Gary Brooke, Dave Thomson, and Martin Taillefer. Reverberation modelling using a parabolic equation method. DRDC Atlantic Contract Report 2012-077, Maritime Way Scientific Ltd., 2110 Blue Willow Crescent, Ottawa ON, K1W IK3 Canada, 2012. Contract W7707-12517/001/HAL, Draft, 2012-Mar-31; 114 pp.

[HE09]   Charles W. Holland and Dale D. Ellis. Two modeling approaches for reverberation in a shallow water waveguide where the scattering arises from a sub-bottom interface. *J. Comp. Acoust.*, 17(1):29–43, 2009.

[HE11]   Charles W. Holland and Dale D. Ellis. Can slowly varying sediment layers respond like a discrete target? *J. Acoust. Soc. Am.*, 130(4, Pt. 2):2339, 2011. Abstract 1pAOb5. Special session on "Steven Schock Session on Acoustic Bottom Characterization and Subbottom Imaging Including Buried Objects," 162nd Meeting of Acoustical Society of America, 31 Oct – 4 Nov 2011, San Diego, CA, USA; 8 slides.

[HE12]   Charles W. Holland and Dale D. Ellis. Clutter from non-discrete seabed structures. *J. Acoust. Soc. Am.*, 131(6):4442–4449, 2012.

[Hol02]   C. W. Holland. Coupled scattering and reflection measurements in shallow water. *IEEE J. Oceanic Eng.*, 27:454–470, 2002.

[HOSH10] Paul C. Hines, John C. Osler, Jeffrey G. E. Scrutton, and Landon J. S. Halloran. Time-of-flight measurements of acoustic wave speed in a sandy sediment at 0.6–20 kHz. *IEEE J. Oceanic Eng.*, 35(3):502–515, 2010.

[PB11]   John S. Papadakis and Leif Bjørnø, editors. *4th International Conference on Underwater Acoustic Measurements: Technologies and Results*, 2011. Conference held at Kos island, Greece, 20–24 June 2011.

[PE08]   John R. Preston and Dale D. Ellis. Report on a normal mode and Matlab based reverberation model. Technical Memorandum TM 2006-290, DRDC Atlantic, Dartmouth, NS, Canada, June 2008.

[PE11]   John R. Preston and Dale D. Ellis. A MATLAB and normal mode based adiabatic range-dependent reverberation model. In Papadakis and Bjørnø [PB11], pages 667–674. Invited paper in Structured Session "Temporal and Spatial Variability of Clutter, Reverberation and Propagation".

[PE12]   John R. Preston and Dale D. Ellis. An adiabatic normal mode reverberation and clutter model. In *Proceedings of the 11th European Conference on Underwater Acoustics*, pages 239–246, 2012. Conference held in Edinburgh, Scotland, UK, 2–6 July 2012; file p48.pdf on CD.

[Pre07]   John R. Preston. Using triplet arrays for reverberation analysis and inversions. *IEEE J. Oceanic Eng.*, 32(4):879–896, 2007.

[PT07]   John S. Perkins and Eric I. Thorsos. Overview of the reverberation modeling workshops. *J. Acoust. Soc. Am.*, 122:3074, 2007. Abstract 4aUW1. Special session on "Underwater Reverberation Measurements and Modeling," 154th Meeting of Acoustical Society of America, New Orleans, LA, USA, 27 Nov – 1 Dec 2007.

[PT09]   John S. Perkins and Eric I. Thorsos. Update on the reverberation modeling workshops. *J. Acoust. Soc. Am.*, 126(4, Pt. 2):2208, 2009. Abstract 2aUW1. Special session on "Reverberation Measurements and Modeling," 158th Meeting of Acoustical Society of America, San Antonio, TX, USA, 26–30 October 2009.

[Rub80]   Louis A. Rubano. Acoustic propagation in shallow water over a low-velocity bottom. *J. Acoust. Soc. Am.*, 67:1608–1613, 1980.

[SH99]   Martin Siderius and Jean-Pierre Hermand. Yellow Shark Spring 1995: Inversion results from sparse broadband acoustic measurements over a highly range-dependent soft clay layer. *J. Acoust. Soc. Am.*, 106:637–651, 1999.

[TH12]   D. Tang and B. T. Hefner. Measurement issues in mid-frequency reverberation experiments. In *Proceedings of the 11th European Conference on Underwater Acoustics*, pages 1071–1076, 2012. Conference held in Edinburgh, Scotland, UK, 2–6 July 2012; file p200.pdf on CD.

[TP08]   Eric I. Thorsos and John S. Perkins. Overview of the reverberation modeling workshops. In Peter L. Nielsen, Chris H. Harrison, and Jean-Claude Le Gac, editors, *International Symposium on Underwater Reverberation and Clutter*, pages 3–14. NATO Undersea Research Centre, La Spezia, Italy, 2008. Conference held at Villa Marigola, Lerici, Italy, 9–12 September 2008.

[ZAS10] Mario Zampolli, Michael A. Ainslie, and Pieter Schippers. Scenarios for benchmarking range-dependent active sonar performance models. *Proc. Institute of Acoustics*, 32, Pt. 2:53–63, 2010.

PUBLICATIONS

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

- Charles W. Holland and Dale D. Ellis. Clutter from non-discrete seabed structures. *J. Acoust. Soc. Am.*, 131(6):4442–4449, 2012. [refereed, published]

- Dale D. Ellis. Calculations of reverberation and fathometer returns at short times using a straight-line ray-path model. Technical Memorandum TM 2011-323, DRDC Atlantic, Dartmouth, NS, Canada, February 2012. 40 pp. [published]

- John R. Preston and Dale D. Ellis. An adiabatic normal mode reverberation and clutter model. In *Proceedings of the 11th European Conference on Underwater Acoustics*, pages 239–246, 2012. Conference held in Edinburgh, Scotland, UK, 2–6 July 2012; file p48.pdf on CD. [published]

- Dale D. Ellis, John R. Preston, and Gary H. Brooke. Progress on the DRDC Clutter Model. In *Proceedings of the 11th European Conference on Underwater Acoustics*, pages 1490–1497, 2012. Conference held in Edinburgh, Scotland, UK, 2–6 July 2012; file p274.pdf on CD. [published]

- Dale D. Ellis and Sean P. Pecknold. Reverberation and target echo calculations for range-dependent sonar problems. In *Proceedings of the 11th European Conference on Underwater Acoustics*, pages 1543–1550, 2012. Conference held in Edinburgh, Scotland, UK, 2–6 July 2012; file p287.pdf on CD. [published]

- Michael A. Ainslie, Mario Zampolli, and Dale D. Ellis. The Weston Memorial workshop: Progress to date on the low frequency active sonar scenarios. In *Proceedings of the 11th European Conference on Underwater Acoustics*, pages 1816–1819, 2012. Conference held in Edinburgh, Scotland, UK, 2–6 July 2012; file p345.pdf on CD. [published]

- Michael A. Ainslie, Dale D. Ellis, and Chris H. Harrison. Low frequency bottom reverberation in a Pekeris waveguide with Lambert's rule. *J. Comp. Acoust.* [refereed, submitted]

Distribution list

Document No.: DRDC Atlantic ECR 2012-173

LIST PART 1: Internal Distribution by Centre

1	Author: D. D. Ellis
1	GL/USC: Garry Heard
1	H/US: Daniel Hutt
1	Sean Pecknold
1	Brian Maranda
3	DRDC Atlantic Library

8   TOTAL LIST PART 1

LIST PART 2: External Distribution by DRDKIM

Department of National Defence
1   DRDKIM

Library & Archives Canada
1   Attn: Military Archivist, Government Records Branch

International recipients
1   Office of Naval Research
875 North Randolph Street, Suite 1425, Code 321 OA
Arlington, VA 22203-1995, USA

1   Dr. John R. Preston
Applied Research Laboratory
The Pennsylvania State University
P.O. Box 30
State College, PA 16804, USA

1   Dr. Charles Holland
Applied Research Laboratory
The Pennsylvania State University
P.O. Box 30
State College, PA 16804, USA

5   TOTAL LIST PART 2

13   TOTAL COPIES REQUIRED

This page intentionally left blank.

DOCUMENT CONTROL DATA				
(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)				

1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.) Defence R&D Canada – Atlantic 9 Grove Street P.O. Box 1012 Dartmouth, Nova Scotia B2Y 3Z7	2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.) UNCLASSIFIED (NON-CONTROLLED GOODS) DMC A REVIEW: GCEC JUNE 2010

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

Modeling and Analysis of Target Echo and Clutter in Range-Dependent Bistatic Environments: FY12 Annual Report for ONR

4. AUTHORS (last name, followed by initials – ranks, titles, etc. not to be used)

Ellis, D.D.

5. DATE OF PUBLICATION (Month and year of publication of document.) October 2012	6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.) 16	6b. NO. OF REFS (Total cited in document.) 35

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

External Client Report

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

US Office of Naval Research
875 North Randolph Street, Suite 1425, Code 321 OA
Arlington, VA 22203-1995, USA

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.) N00014-11-1-0476 (grant)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)

10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.) DRDC Atlantic ECR 2012-173	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification.)

Unlimited

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.))

Unlimited

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Reverberation; Clutter; Target echo; Modelling; Active Sonar; Normal modes; Adiabatic; Range-dependence; Bistatic reverberation; Feature scattering; Towed arrays; Cardioid beam pattern; GEBCO bathymetry; Gulf of Mexico; Clutter Model; TREX13, Sub-bottom scattering