Measurements and Analysis of Reverberation, Target Echo, and Clutter

Dale D. Ellis
DRDC Atlantic, P. O. Box 1012, Dartmouth, NS, Canada B2Y 3Z7
phone: (902)426-3100 ext 104 fax: (902)426-9654 email: dale.ellis@drdc-rddc.gc.ca

Grant Numbers: N000140610830, N000140310420
http://www.onr.navy.mil/sci_tech/32/321/ocean_acoustics.asp

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 continuation of a joint collaboration (N000140310420) between Defence Research & Development Canada – Atlantic (DRDC Atlantic) and the Applied Research Laboratory of Penn 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. A fast shallow water sonar model that includes target echo and clutter is being developed and validated. Experiments will be proposed for the 2007 clutter experiment with NURC, and the data analyzed.

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 in their own institutions. DRDC Atlantic generally funds Dr. Preston for two weeks of research in Canada. The main objective 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.

This project emphasizes examination and interpretation of data from several towed arrays with directional elements – specifically the NURC and ONR cardioid arrays with triplet elements and the DRDC DASM (Directional Array Sensor Module) array with omni/dipole sensors. Models are being extended to compare the performance of these arrays. Data from the Boundary 04 and BASE '04 sea trials are being analyzed along the lines of previous experiments [Preston/Ellis, 1999, 2001; Hines et al., 2001; Preston el al., 2004; Holland et al., 2005]. Experiments will be designed for the 2007 joint US/Canada/NURC Wideband LFAS Clutter Characterization Experiment in the Mediterranean, and the results analyzed.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE **Measurements and Analysis of Reverberation, Target Echo, and Clutter**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Defence Research and Development Canada Atlantic,P. O. Box 1012,Dartmouth, NS, Canada B2Y 3Z7,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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 [Ellis et al., 1997] and feature scattering. 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., 1997; 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.

WORK COMPLETED

Two manuscripts from previous years collaboration on the 2000-2003 Boundary Interaction Joint Research Project were published in the IEEE Special Issue on Interaction of Low- to Mid-Frequency Sound with the Ocean Bottom [Preston et al., 2005; Holland et al., 2005].

A comparison was made between the effect of cardioid sensors versus limaçon sensors on reverberation received on a towed array [Ellis, 2006]. Some highlights are shown in the "Results" section below.

The fast normal mode reverberation model (NOGRP) was extended (and renamed Rosella) to include beam patterns and to handle target echo and signal excess calculations. Initial comparison was made with towed array reverberation and feature-scattering data obtained in the Boundary 04 / BASE '04 sea trial in the Mediterranean [Ellis and Pecknold, 2006]. Some highlights are shown in the "Results" section below.

Initial work was done in extending the normal-mode reverberation model to handle scattering from a basement interface, and make comparisons with an energy flux model.

During Dr. Preston's visit to DRDC Atlantic in August 2006, a version of the fast normal-mode approach was implemented using the ORCA normal-mode model together with Matlab scripts for the reverberation calculations. Comparisons were made with NOGRP/Rosella and the Generic Sonar Model [Weinberg, 1984] for a few simple test cases. More comparisons will be made, and results presented at the ONR Reverberation Modeling Workshop in Austin in November 2006.

RESULTS

Effect of directional sensors

An investigation was made on the reduction of reverberation by arrays of directional sensors [Ellis, 2006]. Figure 1 shows polar plots of the various beam pattern responses in the horizontal plane, for a ~15-wavelength array. In the left plot the linear array has equal response (blue solid) at 60° and 300°; when multiplied by the broadside cardioid (green dash-dot line), the combined response (red dashed line) has a much reduced response at 300°, which is only obvious on a dB plot (middle). In the right plot, the linear array has equal response (blue solid) at 30° and 330°, the normalized limaçon response (green dash-dot line) has a null at 330° and the multiplied response (red dashed line) has a single lobe at 30°. Even on a dB plot (not illustrated), the limaçon shows no ambiguous beam.

The limaçon beamforming can be easily implemented with omni/dipole sensors as used in the DRDC DASM array. It is not obvious that the triplet sensors in cardioid arrays can be used to produce a null in the ambiguous beam over a significant bandwidth.

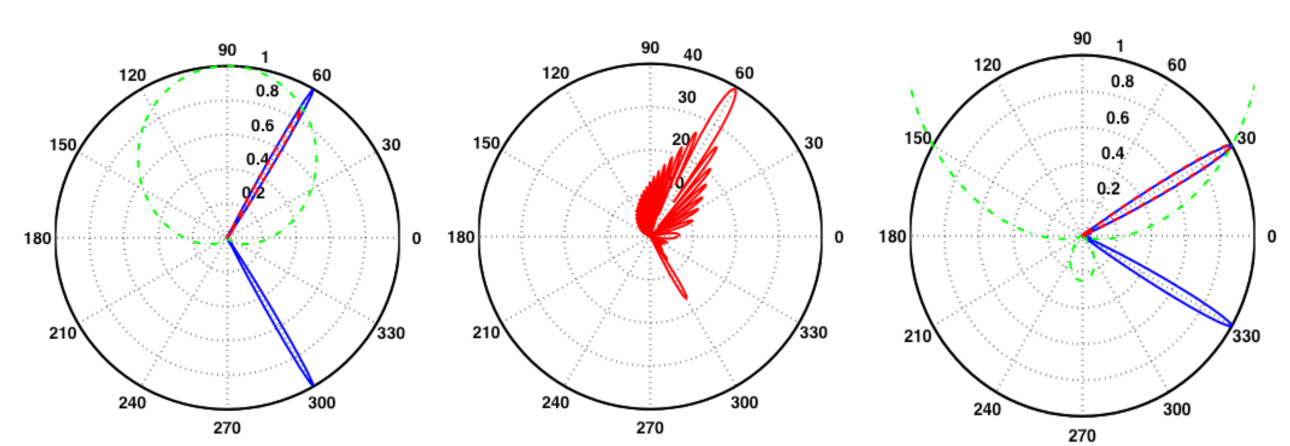

Fig. 1. Polar plots: (left) including cardioid response; (middle) normalized response as a dB plot; (right) including limaçon response.

Figure 2 compares the effective reverberation response of arrays with omnidirectional elements with arrays of cardioid and limaçon sensors. At broadside (left graph) the cardioid and limaçon are identical, and lower than the response for onmidirectional elements. Note that there is not a uniform 3 dB difference as one might naively expect from perfect left/right discrimination; the effective beam pattern is flatter (as a function of vertical angle) for the cardioid/limaçon. If one is using the broadside beam for inversion, it will be important to use the correct effective beam pattern, or else the differences will be attributed to the bottom loss (and result in misleading geoacoustic estimates). Away from broadside (right graph), the cardioid and limaçon arrays produce different results, with the limaçon producing lower reverberation response over most of the angles, and a much flatter response over the vertical angles of interest between the “cusps” (±30°, for a beam 60° from broadside).

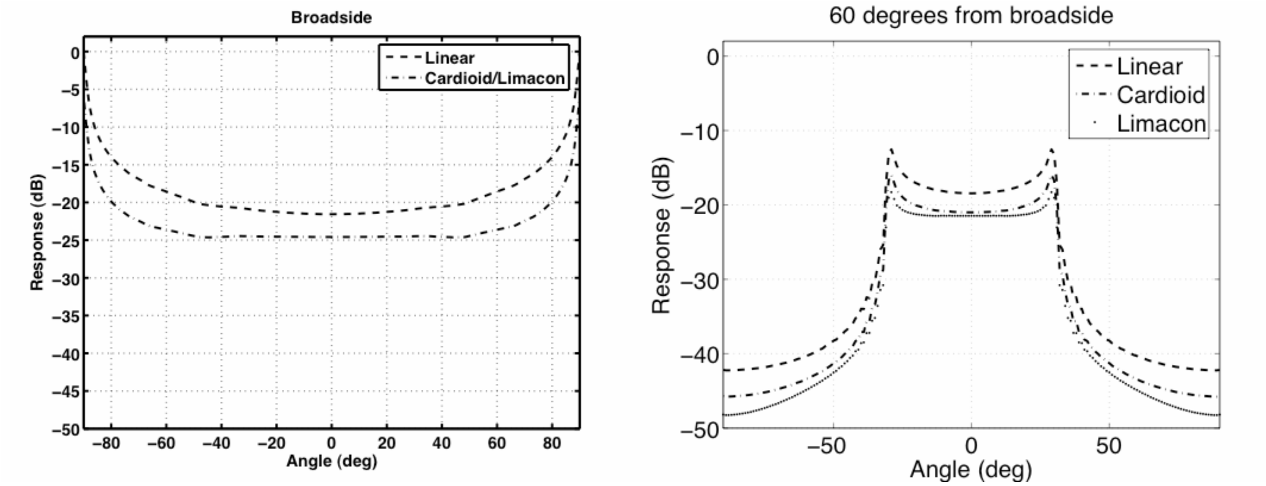

Fig. 2. Effective beam patterns for a 44-λ array: (left) broadside; (right) 60° from broadside.

Figure 3 shows corresponding reverberation response, using the beam patterns of Fig. 2. As one would have anticipated from Fig. 2, at broadside (left graph) the linear array provides over 20 dB reduction of the reverberation compared to a single omnidirectional sensor; the cardioid/limaçon sensors provide about another 3 dB reverberation reduction. Note, even 60° from broadside (right graph) the limaçon sensors, compared to the cardioid sensors, produce only a small additional reduction of reverberation, Figure 1 indicated that limaçon sensors will be much more effective at reducing clutter on the ambiguous beam, but this has not yet been quantified; the Rosella target echo model could be readily adapted to investigate this.

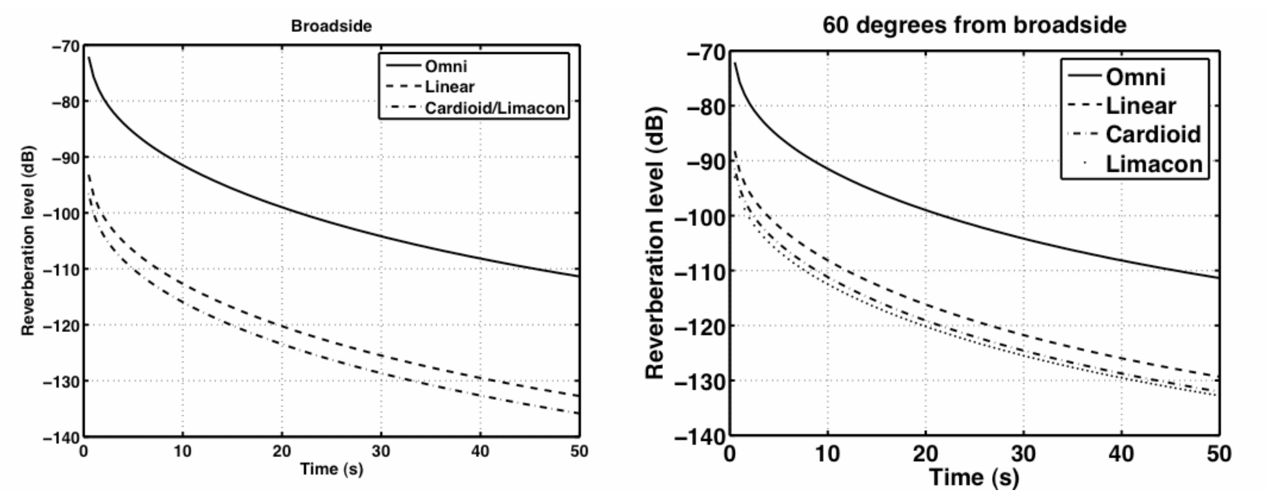

Fig. 3. Reverberation predictions: (left) omni and broadside beams; (right) omni and beams 60° from broadside.

Target echo and signal excess modeling

The normal mode reverberation model was extended to handle beam patterns, target echo, and signal excess calculations. First, the reverberation data on quiet beam – no shipping noise, no major scattering features –was fitted by the model to estimate the scattering strength and bottom reflection loss. Then, the resulting geoacoustic properties were used in the target model to predict the target echo. Figure 4 shows predictions from the Rosella model compared with data taken in the Boundary / BASE '04 sea trials in the Mediterranean [Ellis and Pecknold, 2006]. In the left graph, the target strength of Campo Vega (at 18 s) and oil tender (at 20 s) was estimated from our model predictions to be ~36 dB. In the right graph the target strength of two BBN reflectors [Malme, 1994] (at 10 and 11 s) was fitted from our predictions to be 19 dB. Our estimated BBN target strength is about 7 dB higher than expected from the specification sheet (for a 30 m air-filled hose). The difference could be due to vertical directivity pattern of the BBN hose, 3 to 4 dB errors in the estimated transmission loss, but more validation of the model needs to be done as well.

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.

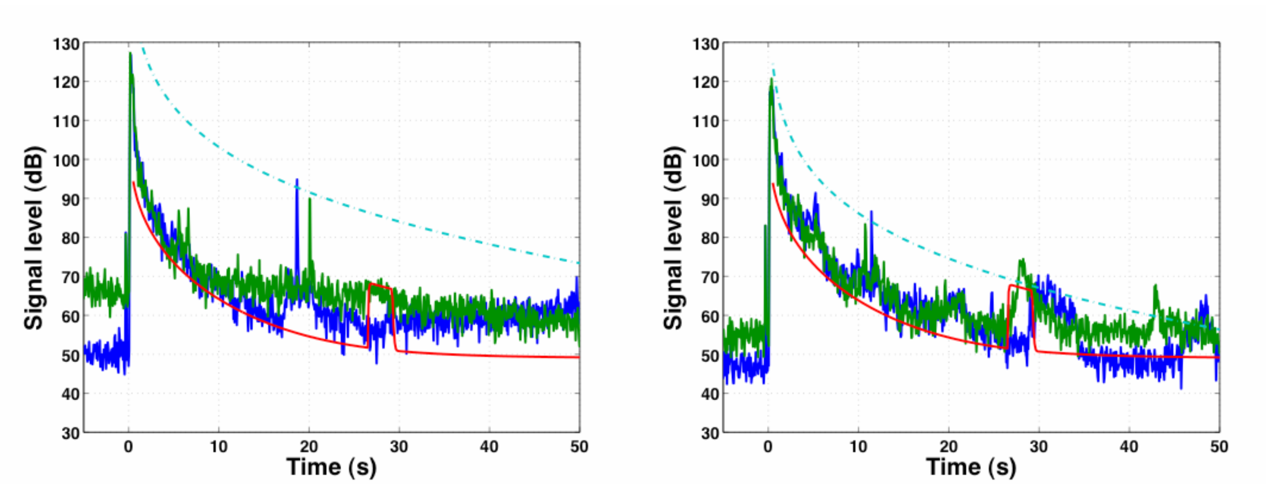

Fig. 4. Comparison of target echo model (dotted line) with echoes (blue, green) from Campo Vega oil rig and tender (left) and BBN targets (right). The red curve is fitted background reverberation, with an arbitrary enhancement of 20 dB between 26 and 29 seconds.

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 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.

RELATED PROJECTS

This project contributes to the US/Canada/NURC Joint Research Project on Wideband Clutter Characterization, 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.

REFERENCES

D. D. Ellis, "A two-ended shooting technique for calculating normal modes in underwater acoustic propagation," DREA Report 85/105, September 1985.

D. D. Ellis, "Effective vertical beam patterns for ocean acoustic reverberation calculations," IEEE J. Oceanic Engineering, **16** (2), 208–211 (1991).

D. D. Ellis, "Shallow water reverberation: normal-mode model predictions compared with bistatic towed-array measurements," IEEE J. Oceanic Engineering, **18** (4) 474–482, (1993).

D. D. Ellis, "A shallow-water reverberation model," J. Acoust. Soc. Am., **97** (5), 2804–2814 (1995).

D. D. Ellis, T. J. Deveau, and J. A. Theriault, "Volume reverberation and target echo calculations using normal modes," in *Oceans '97 MTS/IEEE Conference Proceedings* (IEEE, Piscataway, NY, USA) October 1997, Vol. 1, pp. 608–611.

D. D. Ellis and P. Gerstoft, "Using inversion techniques to extract bottom scattering strengths and sound speeds from shallow-water reverberation data," in *3rd European Conference on Underwater Acoustics* (J. S. Papadakis, ed., FORTH, Heraklion, Crete, Greece) 1996. Vol. 1, pp. 557–562.

D. D. Ellis, J. R. Preston, R. Hollett, and J. Sellschopp, "Analysis of towed array reverberation data from 160 to 4000 Hz during Rapid Response 1997," SACLANTCEN Report SR-280, July 2000. 58 pp.

D. D. Ellis and J. R. Preston, "Extracting sea-bottom information from reverberation data," in CDROM *Collected Papers from the Joint Meeting "Berlin 99"*, Deutsche Gesellschaft für Akustik (DEGA), eds., Universität Oldenburg, Physik/Akustik, Oldenburg, Germany, 1999, Paper 2aUWb10, 4 pp. J. Acoust. Soc. Am., **105** (2), Pt. 2, 1042 (1999).

D. D. Ellis and J. R. Preston, "Boundary 2001 REA: Model-data comparisons at the Strataform and Scotian Shelf sites using GSM and manual fits to the reverberation data," in Proceedings of Boundary/Geoclutter workshop held at DREA, Dartmouth, NS, 2-4 October 2001. 10 pp.

P. C. Hines, N. C. Makris and C. W. Holland, "Proceedings of Geoclutter and Boundary Characterization 2001: Acoustic interaction with the Seabed, Workshop held at DREA, Canada, 2-3 October 2001," DRDC Technical Memorandum DREA TM 2001-185, October 2001. 133 pp.

C. I. Malme, “Development of a high target strength passive acoustic reflector for low-frequency sonar applications,” IEEE J. Oceanic Eng., **19**, 438–448 (1994).

J. R. Preston, "Bottom parameter extraction from long range reverberation measurements," Proceedings of Oceans 2001, Honolulu, Hawaii, IEEE, November 2001.

J. R. Preston, "Shallow water ocean reverberation data analysis and extraction of seafloor geoacoustic parameters in the 100–400 Hz region," Ph. D. Thesis, Penn State University, August 2002.

J. R. Preston and D. D. Ellis, "Summary of bottom reverberation findings and model/data comparisons during three rapid environmental assessment trials," in CDROM *Collected Papers from the Joint Meeting "Berlin 99"*, Deutsche Gesellschaft für Akustik (DEGA), eds., Universität Oldenburg, Physik/Akustik, Oldenburg, Germany, 1999, Paper 2aUWb3, 4 pp. J. Acoust. Soc. Am., **105** (2), Pt. 2, 1040 (1999).

J. R. Preston, D. D. Ellis, R. C. Gauss, and P. L. Nielsen, “Wide-area geoacoustic parameter extraction on the Malta Plateau: reverberation and propagation results from the Boundary Characterization 2000 Experiment, “ NURC Report SM-412, March 2004. 74 +vi pp.

J. Sellschopp, "Rapid environmental assessment for naval operations," SACLANT Undersea Research Centre, SR-328, May 2000.

H. Weinberg, "The Generic Sonar Model," Naval Underwater Systems Center, New London, CT, USA, Technical Document 5971D, June 1985.

B. G. Whitehouse, P. Hines, D. Ellis, and C. N. Barron, “Rapid Environmental Assessment within NATO,” Sea Technology, Vol. 45 (11), November 2004, pp 10-14.

PUBLICATIONS

John R. Preston, Dale D. Ellis and Roger C. Gauss, “Geoacoustic parameter extraction using reverberation data from the 2000 Boundary Characterization Experiment on the Malta Plateau,” IEEE J. Oceanic Eng., **30** (4), 709–732 (2005). In Special Issue on Interaction of Low- to Mid-Frequency Sound with the Ocean Bottom. [published, refereed]

C. W. Holland, R. C. Gauss, P. C. Hines, P. Nielsen, J. R. Preston, C. H. Harrison, D. D. Ellis, K. D. LePage, J. Osler, R. W. Nero, D. Hutt, and A. Turgut, “Boundary Characterization experiment

series overview*,"* IEEE J. Oceanic Eng., **30** (4), 784–806 (2005). In Special Issue on Interaction of Low- to Mid-Frequency Sound with the Ocean Bottom. [published, refereed]

D. D. Ellis and S. P. Pecknold, "Quantitative analysis of reverberation and feature scattering echoes received on a directional towed array," in Proceedings of the Eighth European Conference on Underwater Acoustics – ECUA '06, S. M. Jesus and O. C. Rodriguez, eds., (Tipografia Uniao, Carvoeiro, Portugal) pp. 243–248. [published]

D. D. Ellis, "Effect of cardioid and limaçon directional sensors on towed array reverberation response," Canadian Acoustics **34** (3) Sept. 2006, 102–103. [published]