



Measurements and analysis of reverberation, target echo, and clutter

*FY10 Annual Report for Office of Naval Research Grant
N00014-06-1-0830*

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DRDC Atlantic*

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Defence R&D Canada warrants that the work was performed in a professional manner conforming to generally accepted practices for scientific research and development.

This report is not a statement of endorsement by the Department of National Defence or the Government of Canada.

Defence R&D Canada – Atlantic

External Client Report
DRDC Atlantic ECR 2010-208
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Abstract

This is the Fiscal Year 2010 annual report by the PI to the US Office of Naval Research (ONR) for Grant N00014-06-1-0830: “Measurements and analysis of reverberation, target echo, and clutter.” The main accomplishments for the year were: (i) completion of a report on monostatic reverberation calculations over a sloping bottom; (ii) development of a bistatic range dependent clutter model that includes towed array beam patterns; (iii) calculations of time spreading of scattering features and target echo and their effect on signal excess; (iv) additional work on fathometer returns and reverberation at short times. The most significant accomplishment was the bistatic range-dependent clutter model based on adiabatic modes; it is computationally efficient and is being implemented in the DRDC Sonar Test Bed for potential use by the Canadian Forces.

Résumé

Le présent document est le rapport pour l'exercice 2010 présenté par le chercheur principal à l'Office of Naval Research (ONR) des États-Unis pour la subvention N00014-06-1-0830 : «*Measurements and analysis of reverberation, target echo, and clutter* » (Mesures et analyse de la réverbération, des échos de cible et du fouillis d'écho). Les principales réalisations pour l'année ont été les suivantes : (i) achèvement d'un rapport sur les calculs de réverbération monostatique sur un fond en pente ; (ii) mise au point d'un modèle à fouillis d'échos dépendant de la portée bistatique, incluant des modèles de faisceaux remorqués ; (iii) calculs de la répartition temporelle des caractéristiques de diffusion et échos de cible et leurs effets sur l'excès de signaux ; (iv) travaux additionnels sur les sondeurs à ultrasons et la réverbération de courte durée. La réalisation la plus importante a été le développement d'un modèle de fouillis d'échos basé sur des modèles adiabatiques et dépendant de la portée bistatique. Ce modèle est efficace sur le plan des calculs et une version initiale peut être utilisée sur une plateforme Windows ; une version Unix est mise en œuvre dans le banc d'essai des systèmes de RDDC et pourrait être utilisée par les Forces canadiennes.

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Executive summary

Measurements and analysis of reverberation, target echo, and clutter: FY10 Annual Report for Office of Naval Research Grant N00014-06-1-0830

Dale D. Ellis; DRDC Atlantic ECR 2010-208; Defence R&D Canada – Atlantic; December 2010.

Background: The Principal Investigator (PI) spends three months per year at the Applied Research Laboratory of The Pennsylvania State University, funded by the US Office of Naval Research (ONR). Each year a short Annual Report needs to be submitted to ONR.

Principal results: This is the Fiscal Year 2010 annual report by the PI to the US Office of Naval Research (ONR) for Grant N00014-06-1-0830: “Measurements and analysis of reverberation, target echo, and clutter.” The main accomplishments for the year were: (i) completion of a report on monostatic reverberation calculations over a sloping bottom; (ii) development of a bistatic range dependent clutter model that includes towed array beam patterns; (iii) calculations of time spreading of scattering features and target echo and their effect on signal excess; (iv) additional work on fathometer returns and reverberation at short times. The most significant accomplishment was the bistatic range-dependent clutter model based on adiabatic modes. It is computationally efficient and an initial version is working on a Windows platform; a Unix version is being implemented in the DRDC System Test Bed for potential use by the Canadian Forces.

Significance of results: Many clutter and target echo measurements have been made in the US/Canada/NURC joint experiments “Clutter 07” and “Clutter 09” on the Malta Plateau. A model to simulate some of the results was needed. The recently-developed clutter model will enable some quantitative comparisons to be made in a range-dependent environment. The model is computationally efficient, and allows direct comparisons with towed array beam time series. It thus has potential use for further development as a tactical tool for operational exercises.

The ONR Reverberation Modeling Workshops in 2006 and 2008 have stimulated work by a number of researchers. In previous years the PI’s normal mode reverberation model was shown to be in good agreement with predictions from other models at intermediate and long ranges/times. More recently a ray model has been developed to investigate behaviour at short times. In collaboration with other researchers these short and long range effects are being incorporated into a “benchmark” against which other models can be evaluated.

The next step, modelling the target echo, is critical to sonar performance prediction. The PI’s normal mode model includes the time spreading, and initial results indicate that time

spreading causes drop in signal excess which is of the order of 5 dB. This is consistent with calculations from other models presented at the 2010 Workshop on Validation of Sonar Performance Assessment Tools, and indicates that sonar models will need to incorporate the effects of time spreading.

Future work: The “benchmark” paper on one of the Reverberation Modeling Workshop problems is almost ready for submission to a journal. The time spreading work should also be incorporated into a journal article. The initial version of the Clutter Model is ready to be implemented into the DRDC Sonar Test Bed; considerable refinement of the computational engine is needed, but the architecture should allow easy upgrades. Model validation will focus on range-dependence, target echo, and benchmarks for sonar performance assessment.

Sommaire

Measurements and analysis of reverberation, target echo, and clutter: FY10 Annual Report for Office of Naval Research Grant N00014-06-1-0830

Dale D. Ellis ; DRDC Atlantic ECR 2010-208 ; R & D pour la défense Canada – Atlantique ; décembre 2010.

Introduction : Le chercheur principal (CP) passe trois mois par année à l'Office of Naval Research of The Pennsylvania State University, financé par le US Office of Naval Research (ONR). À chaque année, un court rapport annuel doit être présenté à l'ONR.

Résultats : Le présent document est le rapport pour l'exercice 2010 présenté par le chercheur principal à l'Office of Naval Research (ONR) des États-Unis pour la subvention N00014-06-1-0830 : «*Measurements and analysis of reverberation, target echo, and clutter*» (Mesures et analyse de la réverbération, des échos de cible et du fouillis d'écho). Les principales réalisations pour l'année ont été les suivantes : (i) achèvement d'un rapport sur les calculs de réverbération monostatique sur un fond en pente ; (ii) mise au point d'un modèle à fouillis d'échos dépendant de la portée bistatique, incluant des modèles de faisceaux remorqués ; (iii) calculs de la répartition temporelle des caractéristiques de diffusion et échos de cible et leurs effets sur l'excès de signaux ; (iv) travaux additionnels sur les sondeurs à ultrasons et la réverbération de courte durée. La réalisation la plus importante a été le développement d'un modèle de fouillis d'échos basé sur des modèles adiabatiques et dépendant de la portée bistatique. Ce modèle est efficace sur le plan des calculs et une version initiale peut être utilisée sur une plateforme Windows ; une version Unix est mise en œuvre dans le banc d'essai des systèmes de RDDC et pourrait être utilisée par les Forces canadiennes.

Portée : Beaucoup de mesures de fouillis d'échos et d'échos de cible ont été effectuées lors des expériences conjointes États-Unis/Canada/NURC appelées « Clutter 07 » et « Clutter 09 » sur le plateau de Malte. Un modèle visant à simuler certains des résultats était requis. Le modèle de fouillis d'échos mis au point récemment permettra d'effectuer certaines comparaisons quantitatives pour un milieu dépendant de la portée. Le modèle est efficace sur le plan des calculs et permet d'effectuer des comparaisons directes avec les séries temporelles des faisceaux remorqués. Il pourrait donc être utilisé pour les développements ultérieurs à titre d'outil tactique pour les exercices opérationnels.

Les ateliers de l'ONR sur la modélisation de la réverbération en 2006 et en 2008 ont stimulé un certain nombre de chercheurs à réaliser des travaux. Au cours des années précédentes, le modèle de réverbération en mode normal du chercheur principal s'est avéré en bonne

concordance avec les prévisions d'autres modèles pour les portées/durées de durée intermédiaire et de longue durée. Plus récemment, un modèle de rayon a été mis au point pour examiner le comportement dans les courtes durées. En collaboration avec d'autres chercheurs, ces effets sur les courtes et longues portées sont intégrés dans un « points de référence » avec lequel d'autres modèles peuvent être évalués.

La prochaine étape, qui consiste à modéliser l'écho de la cible, est critique pour la prévision du rendement d'un sonar. Le modèle normal du chercheur principal comprend la répartition temporelle, et les résultats initiaux montrent que la répartition temporelle entraîne une baisse des excès de signaux, de l'ordre de ~ 5 dB. Cela est conforme aux calculs effectués à l'aide d'autres modèles qui ont été présentés lors de l'atelier de 2010 sur la Validation des outils d'évaluation du rendement des sonars, et nous permet de conclure que les modèles de sonars devront intégrer les effets de la répartition temporelle.

Recherches futures : Le document sur les « repère » portant sur l'un des problèmes soulevés lors de l'atelier sur la modélisation de la réverbération est presque prêt à être présenté à un journal. Les travaux sur la répartition temporelle devraient également être intégrés à un article de journal. La version initiale du modèle de fouillis d'échos est prête à être mise en œuvre dans le banc d'essai des sonars de RDDC ; un peaufinement considérable du moteur de calcul est requis, mais l'architecture devrait permettre des mises à niveau faciles. La validation du modèle portera essentiellement sur la dépendance à la distance, sur l'écho de la cible et sur les repères destinés à l'évaluation du rendement des sonars.

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1 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.

2 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.

3 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 [1–3] have been a focus for collaboration. The PI extended and exercised two of his models on a number of problems [4], and collaborated with Preston in developing a Matlab-based model [5]. 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 [6, 7]. A paper with Holland has been published [8], and the paper with Ainslie is in progress. Sub-bottom scattering from the collaboration with Holland [8] 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 modeling and target echo calculations, both of which are important for developing a “Clutter Model”.

4 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 [9].

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 a significant effect for feature scattering and target echo [10, 11]. A presentation was made at the October 2009 meeting of the Acoustical Society of America [12], and at the Weston Symposium [13]. 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 [14].

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 [15] 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 [16].

As part of the model development for model-data comparisons, the fast shallow-water reverberation model [4, 10] based on normal modes has been extended to a bistatic, range-dependent clutter model that includes target echo and feature scattering [17–19]. The formulation based on adiabatic modes had been developed earlier [17] 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 [19]. 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 [20]. 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.

5 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

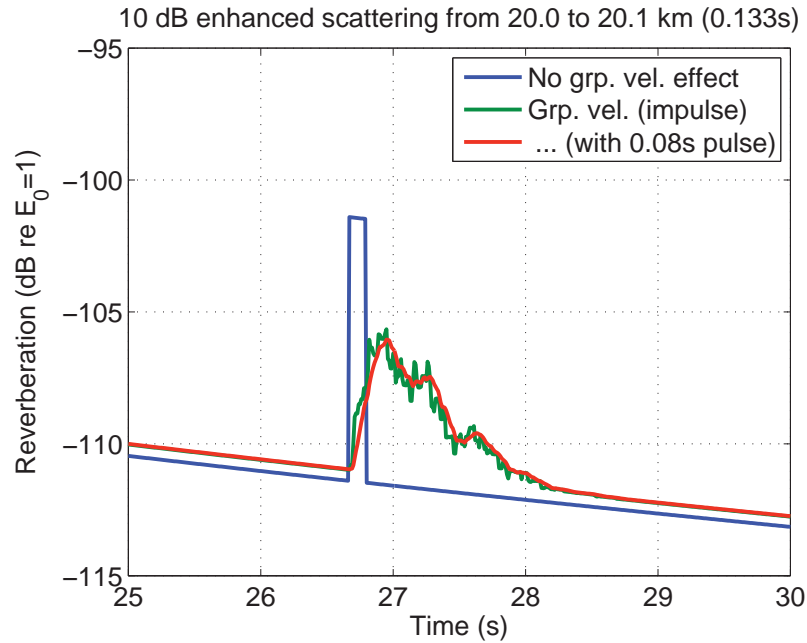


Figure 1: Reverberation structure at 250 Hz from a scattering annulus enhanced by 10 dB for 100 m extent in range.

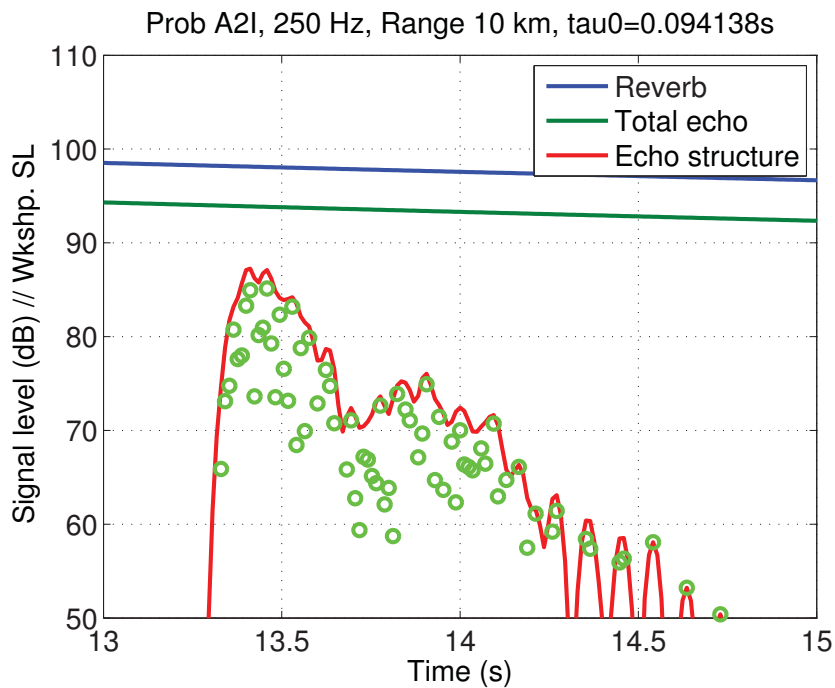


Figure 2: Echo time structure for a point target at range 10 km.

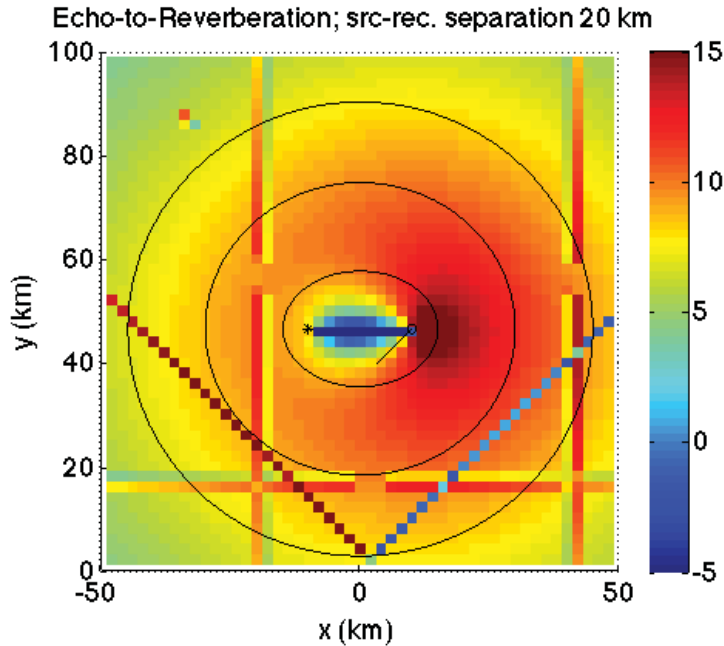


Figure 3: Echo-to-reverberation ratio in 100 by 100 km area using ideal beam patterns. The source is indicated by a *, and the receiver by a \circ with heading 225° indicated by the short line; the time ellipses indicate 20, 40 and 60 s.

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).

Range dependent clutter model

The formulation for a range-dependent clutter model based on adiabatic modes had been developed earlier [17] 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 [19].

Figure 3 shows the signal excess (target echo-to-reverberation level in dB) on a grid generalized from Fig. 2 in [17]. 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 centre 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

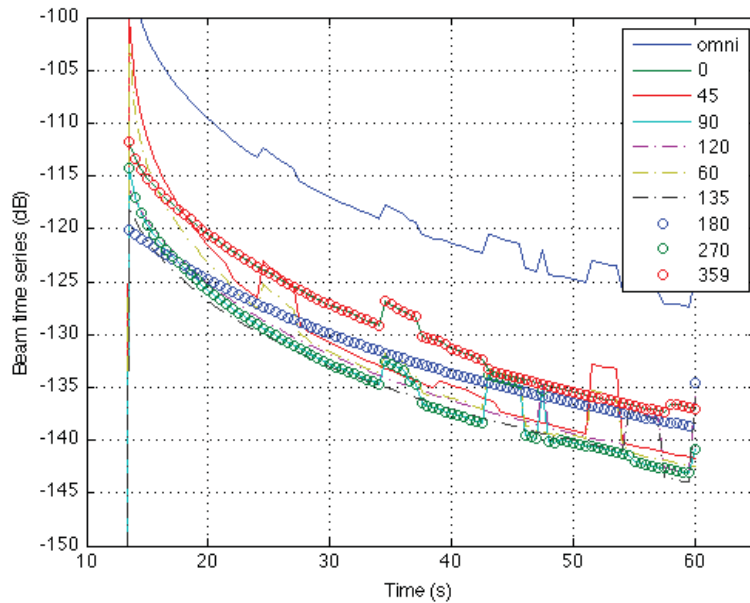


Figure 4: Towed array reverberation beam time series corresponding to Fig. 3.

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 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 [20].

6 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.

7 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 [20] 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.

8 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.

References

- [1] Perkins, J. S. and Thorsos, E. I. (2007), Overview of the reverberation modeling workshops, *J. Acoust. Soc. Am.*, 122, 3074. Abstract 4aUW1. Special session on “Underwater Reverberation Measurements and Modeling”, 154th Meeting of Acoustical Society of America, 27 Nov – 1 Dec 2007, New Orleans, LA, USA.
- [2] Thorsos, E. I. and Perkins, J. S. (2008), Overview of the reverberation modeling workshops, In Nielsen et al. [21], pp. 3–14. Conference held at Villa Marigola, Lerici, Italy, 9–12 September 2008.
- [3] Perkins, J. S. and Thorsos, E. I. (2009), Update on the reverberation modeling workshops, *J. Acoust. Soc. Am.*, 126(4, Pt. 2), 2208. Abstract 2aUW1. Special session on “Reverberation Measurements and Modeling”, 158th Meeting of Acoustical Society of America, 26–30 October 2009, San Antonio, TX, USA.
- [4] Ellis, D. D. (2008), 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.
- [5] Preston, J. R. and Ellis, D. D. (2008), Report on a normal mode and Matlab based reverberation model, Technical Memorandum TM 2006-290, DRDC Atlantic, Dartmouth, NS, Canada.
- [6] Ellis, D. D. and Holland, C. W. (2007), A comparison of two modeling approaches for reverberation in a shallow-water waveguide where the scattering arises from a sub-bottom interface, *J. Acoust. Soc. Am.*, 122, 3091. Abstract 4pUW4. Special session on “Underwater Reverberation Measurements and Modeling”, 154th Meeting of Acoustical Society of America, 27 Nov – 1 Dec 2007, New Orleans, LA, USA.
- [7] Ellis, D. D., Ainslie, M. A., and Harrison, C. H. (2007), A comparison of ray, normal-mode, and energy flux results for reverberation in a Pekeris waveguide, *J. Acoust. Soc. Am.*, 122, 3075. Abstract 4aUW9. Special session on “Underwater Reverberation Measurements and Modeling”, 154th Meeting of Acoustical Society of America, 27 Nov – 1 Dec 2007, New Orleans, LA, USA.
- [8] Holland, C. W. and Ellis, D. D. (2009), A comparison of 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.
- [9] Zampolli, M., Ainslie, M. A., and Schippers, P. (2010), Scenarios for benchmarking range-dependent active sonar performance models, *Proc. Institute of Acoustics*, Vol. 32, Pt.2. [in press].

- [10] Ellis, D. D. (1995), A shallow-water normal-mode reverberation model, *J. Acoust. Soc. Am.*, 97, 2804–2814.
- [11] Ellis, D. D., Deveau, T. J., and Theriault, J. A. (1997), Volume reverberation and target echo calculations using normal modes, In *Oceans '97 MTS/IEEE Conference Proceedings*, Vol. 1, pp. 608–611, IEEE, Piscataway, NY, USA.
- [12] Ellis, D. D. (2009), Target echo and clutter calculations, including time spreading using normal-mode group velocities, *J. Acoust. Soc. Am.*, 126(4, Pt. 2), 2225. Abstract 2pUW6. Special session on “Reverberation Measurements and Modeling”, 158th Meeting of Acoustical Society of America, 26–30 October 2009, San Antonio, TX, USA. 17 slides.
- [13] Ellis, D. D. (2010), Normal Mode and Ray Predictions for the Sonar Performance Assessment Problems, In Ainslie, M. A. and Zampolli, M., (Eds.), *Proceedings of David Weston Sonar Performance Assessment Symposium*, Cambridge, UK. Abstract only.
- [14] Thorsos, E. I., Henyey, F. S., Yang, J., and Reynolds, S. A. (2009), Ray versus mode differences in reverberation modeling solutions for environments with high boundary scattering loss, *J. Acoust. Soc. Am.*, 126(4, Pt. 2), 2209. Abstract 2aUW2. Special session on “Reverberation Measurements and Modeling”, 158th Meeting of Acoustical Society of America, 26–30 October 2009, San Antonio, TX, USA.
- [15] Ellis, D. D. and Franklin, J. B. (1987), The importance of hybrid ray paths, bottom loss, and facet reflection on ocean bottom reverberation, In Merklinger, H. M., (Ed.), *Progress in Underwater Acoustics*, pp. 75–84, International Congress on Acoustics, New York: Plenum Press.
- [16] Ellis, D. D. (2010), Calculations of Reverberation and Fathometer Returns at Short Times, In Ainslie, M. A. and Zampolli, M., (Eds.), *Proceedings of David Weston Sonar Performance Assessment Symposium*, Cambridge, UK. Abstract only.
- [17] Ellis, D. D., Preston, J. R., Hines, P. C., and Young, V. W. (2008), Bistatic signal excess calculations over variable bottom topography using adiabatic normal modes, In Nielsen et al. [21], pp. 97–104. Conference held at Villa Marigola, Lerici, Italy, 9–12 September 2008.
- [18] Kwan, T. and Ellis, D. D. (2010), Reverberation Calculations over Sloping Ocean Bottoms, Technical Memorandum TM 2009-192, DRDC Atlantic, Dartmouth, NS, Canada. 74 pp.
- [19] Ellis, D. D. and Pecknold, S. P. (2010), Range-Dependent Reverberation and Target Echo Calculations using the DRDC Atlantic Clutter Model, *Canadian Acoustics*, 38(3), 72–73.

- [20] Brooke, G. H., Kilistoff, S. J., Thomson, D. J., and Ellis, D. D. (2010), Performance Prediction via the java Acoustic Model Interface, *Canadian Acoustics*, 38(3), 64–65.
- [21] Nielsen, P. L., Harrison, C. H., and Le Gac, J.-C., (Eds.) (2008), International Symposium on Underwater Reverberation and Clutter, NATO Undersea Research Centre, La Spezia, Italy. Conference held at Villa Marigola, Lerici, Italy, 9–12 September 2008.

9 Publications

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

- J. R. Preston and D. D. Ellis. Extracting bottom information from towed-array reverberation data Part I: Measurement methodology. *J. Mar. Syst.*, 78: S359–S371, 2009. [published, refereed]
- 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]

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Annex A: Statistics file

This is a copy of the FY2010 ONR statistics file, OAEllis.txt:

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"STATISTICS FILE" TEMPLATE  
FOR FY2010
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[title] Measurements and Analysis of Reverberation, Target Echo, and Clutter  
[awardNumber1] N000140610830  
[awardNumber2]  
[awardNumberMore]  
[keyWords] reverberation, target echo, clutter, modeling, benchmarks,  
range-dependence, rapid environmental assessment, normal modes,  
time spreading, feature scattering, bistatic  
[specialCat]  
[pi1] Dale D. Ellis  
[pi2]  
[pi3]  
[pi4]  
[pi5]  
[piMore]  
[totalUndergradStudents]  
[totalUndergradWomenStudents]  
[totalUndergradMinorityStudents]  
[totalGradStudents]  
[totalGradWomenStudents]  
[totalGradMinorityStudents]  
[totalPostDocs]  
[totalWomenPostDocs]  
[totalMinorityPostDocs]  
[bestAccomplishment] Development of a working bistatic range-dependent  
reverberation and target echo model with realistic towed array beam patterns  
[comments]
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This is the Fiscal Year 2010 annual report by the PI to the US Office of Naval Research (ONR) for Grant N00014-06-1-0830: "Measurements and analysis of reverberation, target echo, and clutter." The main accomplishments for the year were: (i) completion of a report on monostatic reverberation calculations over a sloping bottom; (ii) development of a bistatic range dependent clutter model that includes towed array beam patterns; (iii) calculations of time spreading of scattering features and target echo and their effect on signal excess; (iv) additional work on fathometer returns and reverberation at short times. The most significant accomplishment was the bistatic range-dependent clutter model based on adiabatic modes; it is computationally efficient and is being implemented in the DRDC Sonar Test Bed for potential use by the Canadian Forces.

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