Modeling and Analysis of Target Echo and Clutter in Range-Dependent Bistatic Environments: FY13 Annual Report for ONR

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LONG-TERM GOALS

The long-term goal of this work is to better understand and model reverberation, 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.

Central to 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. In the last two years the focus has been on experiment design and data analysis for the ONR ”fixed-fixed” mid-frequency reverberation and target echo experiments (GulfEx12 and TREX13) in the Gulf of Mexico near Panama City, Florida [TH12].

Model development to support experiment design and data interpretation is another major focus of the work. Recent work by the PI has concentrated on bistatic range-dependent reverberation modeling and target echo calculations. A bistatic range-dependent "Clutter Model" [EP11, EPB13] based on adiabatic normal modes has been developed, and comparisons made with towed array data from the Malta Plateau. In support of the GulfEx12 and TREX13 experiments, the model was extended to handle towed arrays with triplet elements, and predictions of reverberation and target echo were made [EPB13, EP13b, EP13a].

Over the past few years, the ONR Reverberation Modeling Workshops [PT07, TP08, PT09] have been a fruitful area 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), the 2012 European Conference on Underwater Acoustics (ECUA), and the 2013 Underwater Acoustics Conference (UAC).

WORK COMPLETED

This section summarizes some of the work completed in FY2013.

The main efforts in 2013 were preparations for, and participation in, the 2013 Target and Reverberation Experiment (TREX) held in very shallow water in the Gulf of Mexico off Panama City, FL. Reverberation and target echo experiments were designed, and plans developed for data transfer and analysis by DRDC. The experiment was conducted in April and May 2013, producing a valuable data set. DRDC participated with CFAV Quest, augmenting the ONR reverberation experiments with an echo repeater and passive acoustic target, as well as conducting experiments in continuous active sonar. The data are in an early state of analysis, but an example of the passive echo is shown in the "Results" section below.

In 2012, the Clutter Model [EP10, EP11] was extended to handle left-right ambiguity of the Five Octave Research Array (FORA) triplet array, and preliminary calculations of reverberation and target echo made [EPB13] for the upcoming 2013 TREX experiment. In 2013, analysis of the directional noise background from the 2012 measurements was completed [EP13b], and the model calculations were compared with beam data [EP13b, EP13a]. Papers were presented and published in the proceedings of the 2013 International Congress of Acoustics and the 1st Underwater Acoustics Conference (UAC). An example is given in the "Results" section below.

Work continued on the validation of reverberation and target echo models. The comparisons [AEH11] for the Pekeris model benchmarks are in review at the Journal of Computational Acoustics [AEH13].

The initial work [Ell11, PE11] on range-dependent RMW and Weston Symposium test cases was extended using the author's model r2d3 [EP12], and the Bellhop model [PEM12]. Additional model-model comparisons were made in collaboration with Ainslie et al. [AEE$^+$13].

The PI was co-organizer of a Structured Session on Sonar Performance Modelling and Validation at the 2013 UAC, and contributed two papers [EP13a, AEE$^+$13] of which he was principal author of one.

RESULTS

This section illustrates a few results from the activities mentioned in the previous section. The first example is taken from the paper [EP13a] at the 1st Conference on Underwater Acoustics in Corfu. The second example shows data, including target echoes, from the TREX13 experiment.

Analysis of the GulfEx12 data on FORA

Figure 1 shows the bathymetry and some expected clutter objects at the experiment site. The contours (in m) are from the GEBCO_08 gridded database [GEB10], contoured using Matlab. The source and receiver were at 30° 03.59′ N 85° 40.86′ W (30.05983°N 85.68100°W) in 18.3 m of water.

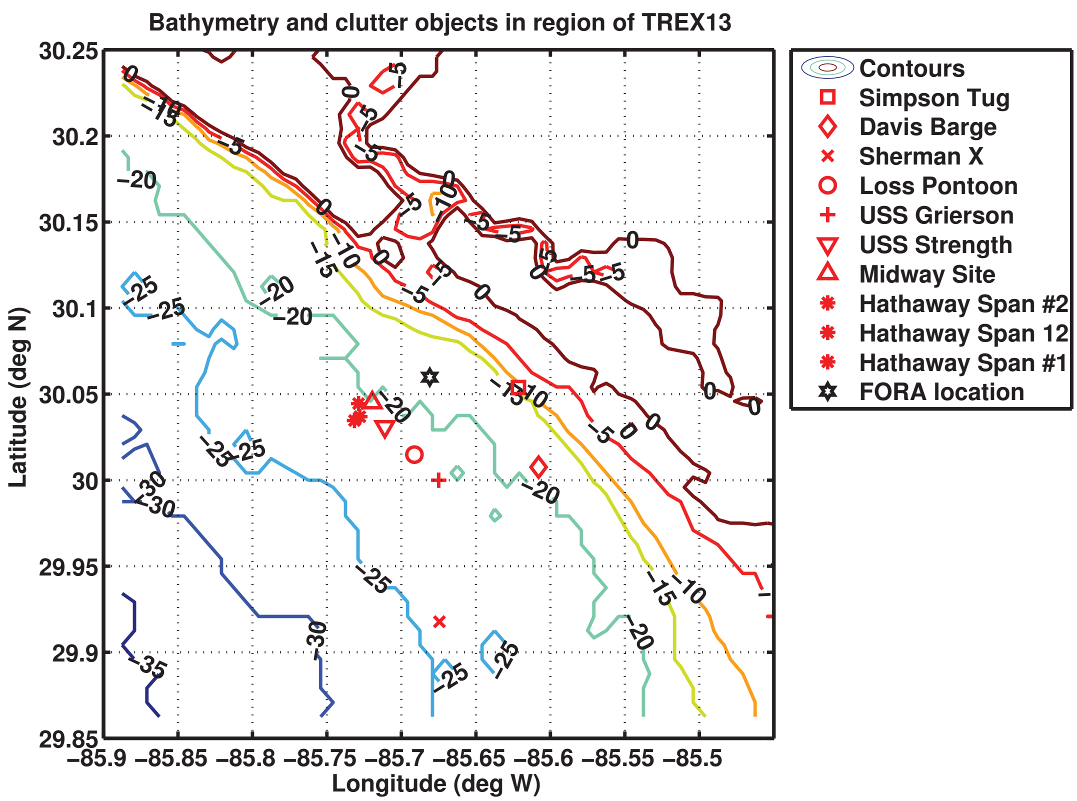

Figure 1: Bathymetry and clutter objects near the experiment. The contours (in m) are from the GEBCO_08 gridded database, contoured using Matlab. The source/receiver location in 18.3 m of water is indicated by the black star.

The receiver was the triplet section of FORA deployed horizontally in a fixed position, 2 m above the bottom. The triplet section of FORA has 78 elements at 0.2 m spacing, which implies a design frequency of 3750 Hz. For this experiment, only a 48-element subsection was working. These 48 working elements were Hann-weighted and used to form 157 beams, 79 equally spaced in the sine of the beam steering angle, from forward to aft endfire on each side. The triplets in each element were used to form broadside cardioids on the appropriate side, except at aft endfire where only beam with the right-looking cardioid was formed.

In 2012, FORA was deployed with the forward endfire beam pointing 7° east of north. The source was an ITC 2015 transducer, operating at 199 dB (re 1 μPa at 1 m). It had an omnidirectional beam pattern and was deployed 1 m off the bottom, 3 m west of the mid-point of the FORA array. Generally, pulses were sent every 30 s; for each pulse, 25 s of data were recorded with 1 s of background noise included before the pulse. The main pulses sent were wt1 (0.8 ms CW at 3500 Hz), wt2 (10 ms CW at 3500 Hz), and wt4 (100 ms LFM from 2500–3500 Hz). Due to its short duration, pulse wt1 has very little energy, and being broadband is spatially-aliased on FORA. Pulse wt4 had enough energy that the resulting reverberation is above the background noise for 5–10 s.

Range-dependent calculations were made using the Clutter Model [EP10, EP11] out to a time of 25 s and presented in 2012 [EPB13]. In 2013 additional short-range model-data comparisons were made for the wt4 pulse and a flat bathymetry of depth 18 m. The water was isovelocity with sound speed 1530 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 (although the model-data comparisons indicate a strength of -29 dB). Calculations were done at a single frequency 3000 Hz, using the average beam patterns over the 2500–3500 Hz band. For the model predictions, the ambient noise on each beam was obtained from a sample of the data before the ping.

Fig. 2 shows model-data differences for four of these pulses. The strong lines from the noisy ship traffic are quite variable, and imperfectly subtracted (especially the lower-left panel where a nearby vessel changed bearing over the recording interval). However, many clutter objects are consistent from ping to ping; there are many other clutter objects in addition to the expected ones (white diamonds).

There is some indication that very near the array (the first 2 or 3 s of data) the reverberation may be correlated with bathymetry and sand waves, or dunes; see Fig. 3 where the sand dune peaks are about 0.5 km apart. Sand dunes, and their migration, are known in this area [Kd10], so the correlation with backscatter merits further investigation. Indeed, one might then try to make a scattering map similar to the rapid environmental assessment approach of Preston and Ellis for longer-range reverberation [PE09].

Polar plot of reverberation and target echo from TREX13 data

A large quantity of excellent data was obtained during the TREX experiment in April and May 2013. Figure 4 shows a polar plot of the model-data differences from Run 82 (1800–2700 Hz LFM source pulse). Locations of some previously-identified wrecks are shown by the white diamonds; the black diamonds indicate locations of the DRDC passive acoustic target and the vertical array of the Marine Physics Laboratory (MPL). For the plot, the FORA array heading was adjusted to be at a bearing of 355°, so the locations of the two targets would line up with the mid bearing of the echoes. The model predictions were for a flat bottom, essentially to provide a "physics-based normalization" to the data, and to emphasize any bottom features. The model predictions were made at the mid-frequency

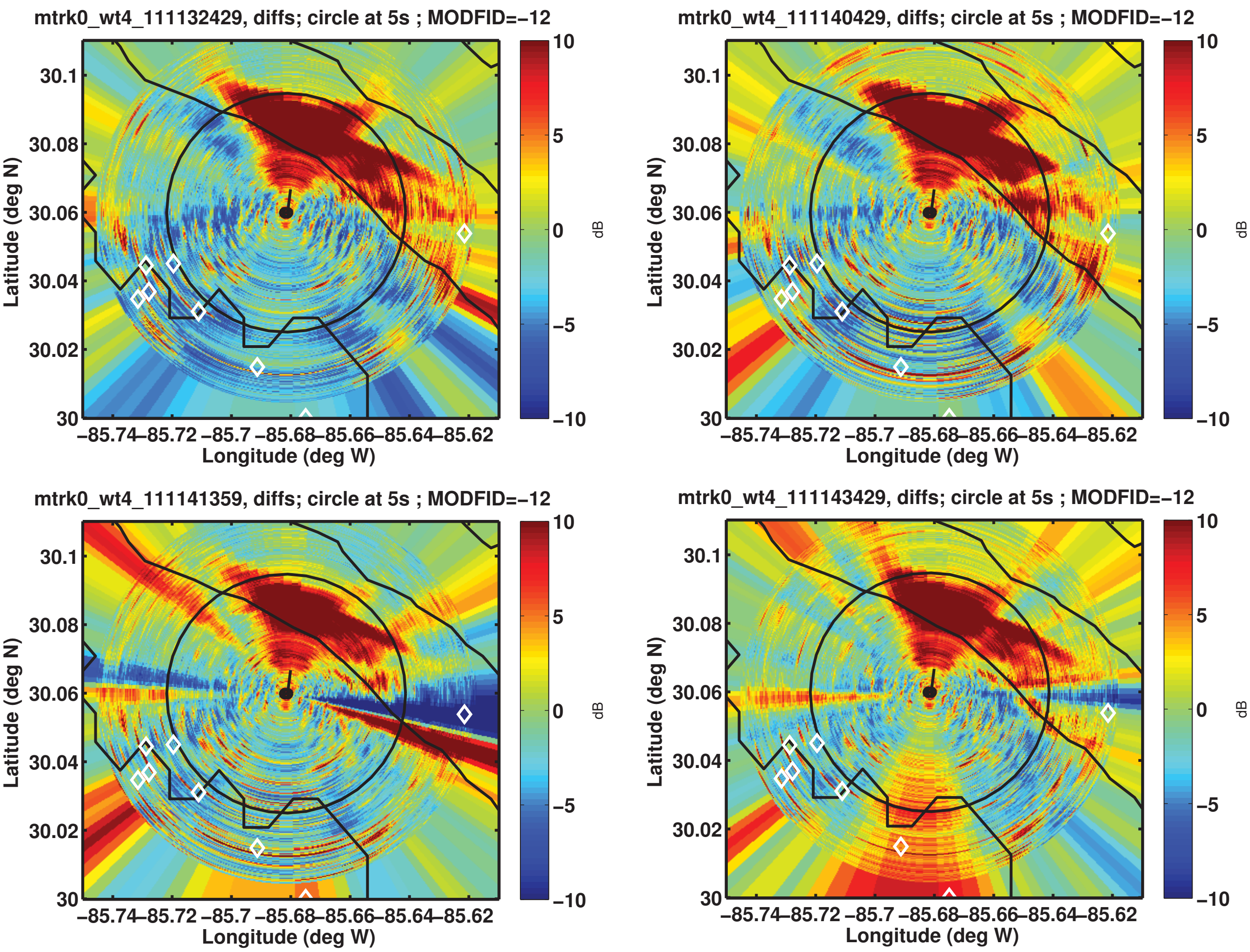

Figure 2: Plots of model-data differences for 4 pulses; model uses flat bathymetry. Note how the clutter objects are consistent ping to ping. There is some indication that very near the receiver the reverberation may be correlated with the bathymetry and sand dunes.

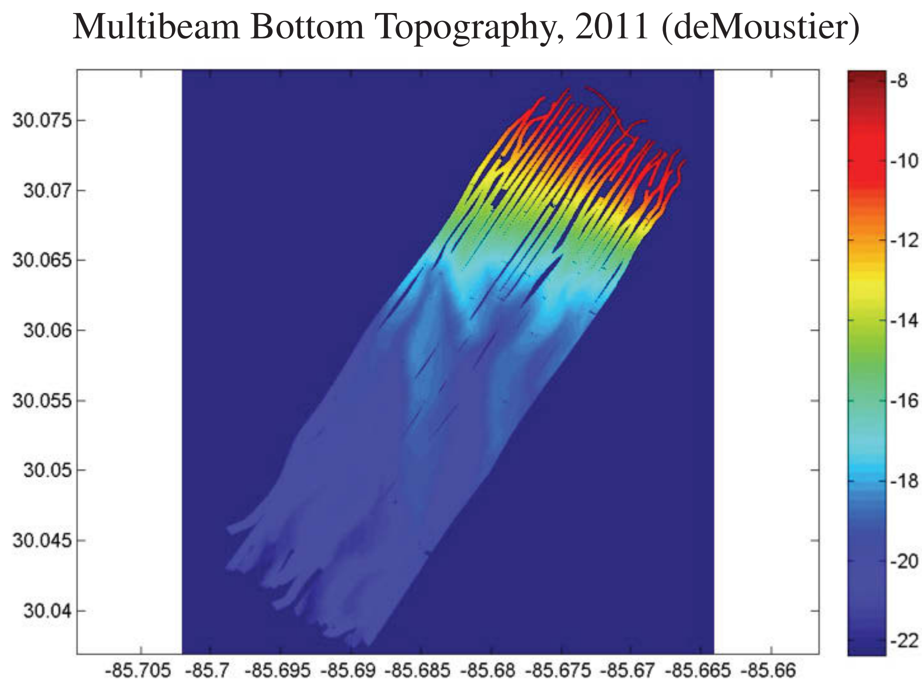

Figure 3: Multibeam survey showing sand waves with peak-to-peak height 1–2 m. (Bathymetry data courtesy of C. de Moustier and B. J. Kraft, HLS Research, Inc.)

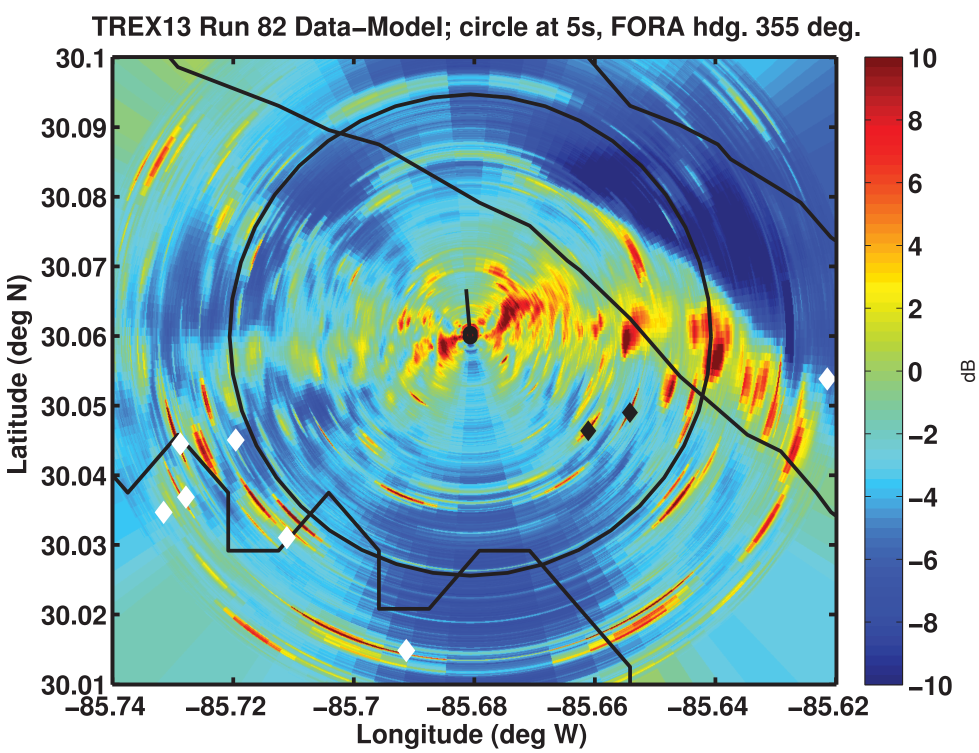

Figure 4: Polar plot of TREX13 model-data differences. Some previously-identified wrecks are denoted by the white diamonds. The black diamonds show the MPL vertical array, and the DRDC passive acoustic target.

2250 Hz, using the average beam patterns over the 1800–2700 Hz band. The model inputs were as noted above for the 2012 GulfEx calculations, except for a 50 m source-receiver separation, sound speed of 1525 m/s, and bottom attenuation doubled to 1.0 dB/m-kHz. The doubling of attenuation was not based on any physics, but was the easiest way to increase the bottom loss to approximate the range dependence of the data.

Quantitative modeling of the transmission loss and reverberation in conjunction with environmental measurements made by other researchers will refine the bottom parameters. More analysis is in progress, especially as to whether the reverberation features can be correlated with the sand dunes mentioned above.

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.

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, and improved in 2012 [BT12]. Further improvements were made by Akoostix Inc. in 2013, and the hope is to be able to fully integrate the Clutter Model into the DRDC System Test Bed for comparison with towed array data.

The newly approved DRDC Technical Demonstration Project AMASE (Advancing Multistatic Active Sonar Employment) can 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.

The main efforts in 2013 were preparations for, and participation in, the ONR sponsored 2013 Target and Reverberation Experiment (TREX) held in very shallow water in the Gulf of Mexico off Panama City, FL. DRDC Atlantic participated, with their research vessel CFAV Quest, providing target echoes and conducting continuous active sonar experiments. Analysis of the data continues in collaboration with scientists at APL/UW, ARL/PSU, TNO (Netherlands), and other US laboratories.

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

[AEE+13] Michael A. Ainslie, Dale D. Ellis, Jan Ehrlich, Pieter Schippers, Karl-Thomas Hjelmervik, and Mathieu E. G. D. Colin. Echo, reverberation and echo to reverberation ratio for isovelocity waveguides related to Weston Memorial Workshop Scenarios A2.I and A2.IV. In John S. Papadakis and Leif Bjørnø, editors, *1st Underwater Acoustic Conference and Exhibition: Proceedings*, pages 425–432, 2013. Conference held in Corfu, Greece, 23–28 June 2013. Invited.

[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, editor. *Validation of Sonar Performance Assessment Tools, A workshop held in memory of David E. Weston, 7–9 April 2010*, volume 32, Pt. 2, 2010. Workshop held at Clare College, Cambridge, UK, 7-9 April 2010.

[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.

[BT12] Gary Brooke and Dave Thomson. Development of Java Acoustic Model Interface (JAMI). DRDC Atlantic Contract Report 2012-105, Brooke Numerical Services, 3440 Seaton Street, Victoria, BC, V8Z 3V9, Canada, 2012. Contract W7707-125424/001/HAL, Draft, 2012-Mar-29; 101 pp.

[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. 84 pp.

[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.

[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, ECUA 2012*, pages 1534–1541, 2012. Conference held in Edinburgh, Scotland, UK, 2–6 July 2012; file p287.pdf on CD, pp. 1543–1550.

[EP13a] Dale D. Ellis and John R. Preston. Comparison of model predictions with reverberation and clutter data in a range-dependent shallow water area. In Papadakis and Bjørnø [PB13], pages 465–472. Conference held at Corfu island, Greece, 23–28 June 2013.

[EP13b] Dale D. Ellis and John R. Preston. An initial model-data comparison of reverberation and clutter from a near-shore site in the Gulf of Mexico. *POMA*, 19(070007), 2013. 9 pp., Proceedings of International Conference on Acoustics, Montreal, Canada, 2–7 June 2013.

[EPB13] Dale D. Ellis, John R. Preston, and Gary H. Brooke. Progress on the DRDC Clutter Model. *POMA*, 17(070097), 2013. 9 pp. From proceedings of the 11th European Conference on Underwater Acoustics held in Edinburgh, Scotland, UK, 2–6 July 2012.

[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/gridded_bathymetry_data/documents/gebco_08.pdf; data file is `gebco_08.nc`, version 20100927.

[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.

[Kd10] B. J. Kraft and C. de Moustier. Detailed bathymetric surveys offshore Santa Rosa Island, FL: Before and after Hurricane Ivan (September 16, 2004). *IEEE J. Oceanic Eng.*, 35(3):453–470, 2010.

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

[PB13] John S. Papadakis and Leif Bjørnø, editors. *1st Underwater Acoustic Conference and Exhibition: Proceedings*, 2013. Proceedings of conference held at Corfu island, Greece, 23–28 June 2013.

[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. 46 pp.

[PE09] John R. Preston and Dale D. Ellis. Extracting bottom information from towed-array reverberation data Part I: Measurement methodology. *J. Mar. Syst.*, 78:S359–S371, 2009.

[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".

[PEM12] Sean P. Pecknold, Dale D. Ellis, and Diana F. McCammon. Range-dependent reverberation and target echo calculations using a Gaussian beam model. *Canadian Acoustics*, 40(3):141, 2012. Abstract. Canadian Acoustics Week, 10–12 October 2012, Banff, AB, Canada. Presented by S. Pecknold; 20 Slides.

[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.

[TH12] D. Tang and B. T. Hefner. Measurement issues in mid-frequency reverberation experiments. In *Proceedings of the 11th European Conference on Underwater Acoustics, ECUA 2012*, pages 1499–1504, 2012. Conference held in Edinburgh, Scotland, UK, 2–6 July 2012; file p200.pdf on CD, pp. 1071–1076.

[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:

- Dale D. Ellis and John R. Preston. An initial model-data comparison of reverberation and clutter from a near-shore site in the Gulf of Mexico. *POMA*, 19(070007), 2013. 9 pp. From proceedings of International Conference on Acoustics, Montreal, Canada, 2–7 June 2013. [published]
- Dale D. Ellis, John R. Preston, and Gary H. Brooke. Progress on the DRDC Clutter Model. *POMA*, 17(070097), 2013. 9 pp. From proceedings of the 11th European Conference on Underwater Acoustics held in Edinburgh, Scotland, UK, 2–6 July 2012. [published]
- Michael A. Ainslie, Dale D. Ellis, Jan Ehrlich, Pieter Schippers, Karl-Thomas Hjelmervik, and Mathieu E. G. D. Colin. Echo, reverberation and echo to reverberation ratio for isovelocity waveguides related to Weston Memorial Workshop Scenarios A2.I and A2.IV. In John S. Papadakis and Leif Bjørnø, editors, *1st Underwater Acoustic Conference and Exhibition: Proceedings*, pages 425–432, 2013. Conference held in Corfu, Greece, 23–28 June 2013. Invited. [published]
- Dale D. Ellis and John R. Preston. Comparison of model predictions with reverberation and clutter data in a range-dependent shallow water area. In John S. Papadakis and Leif Bjørnø, editors, *1st Underwater Acoustic Conference and Exhibition: Proceedings*, pages 465–472, 2013. Conference held in Corfu, Greece, 23–28 June 2013. Invited. [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, in review]

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Reverberation; Clutter; Target echo; Modelling; Active Sonar; Normal modes; Adiabatic; Range-dependence; Bistatic reverberation; Feature scattering; Towed arrays; GEBCO bathymetry; Gulf of Mexico; Clutter Model; TREX13 ; sand dunes