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

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

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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.

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. 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].

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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, 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 made [EPB13, EP13b, EP13a].

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), 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 acoustics 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 done [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 in 18.3 m of water.

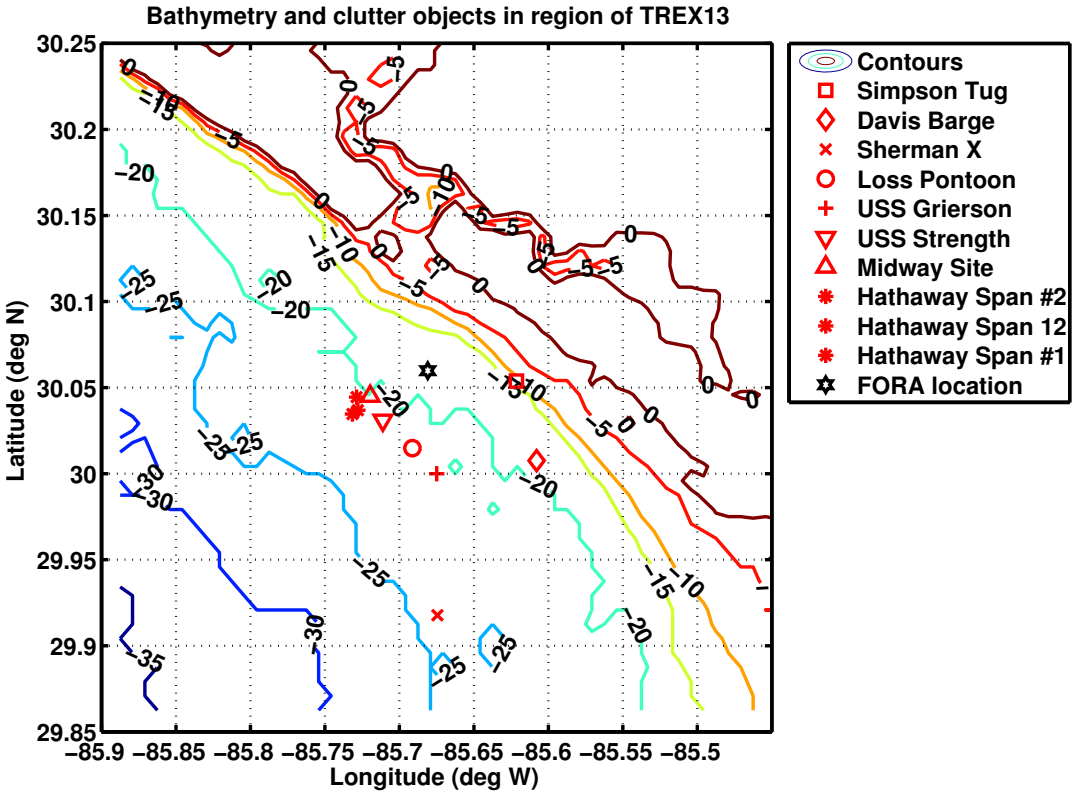

Figure 1: Bathymetry and clutter objects near the experiment. The contours (in m) are from the GEBCO_08 gridded database, contoured using Matlab. The source/receiver location in 18.3 m of water is indicated by the black star.

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 the right-looking cardioid was used.

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 in 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 2250 Hz, using the average beam patterns over the 1800–2700 Hz band. The model inputs were as

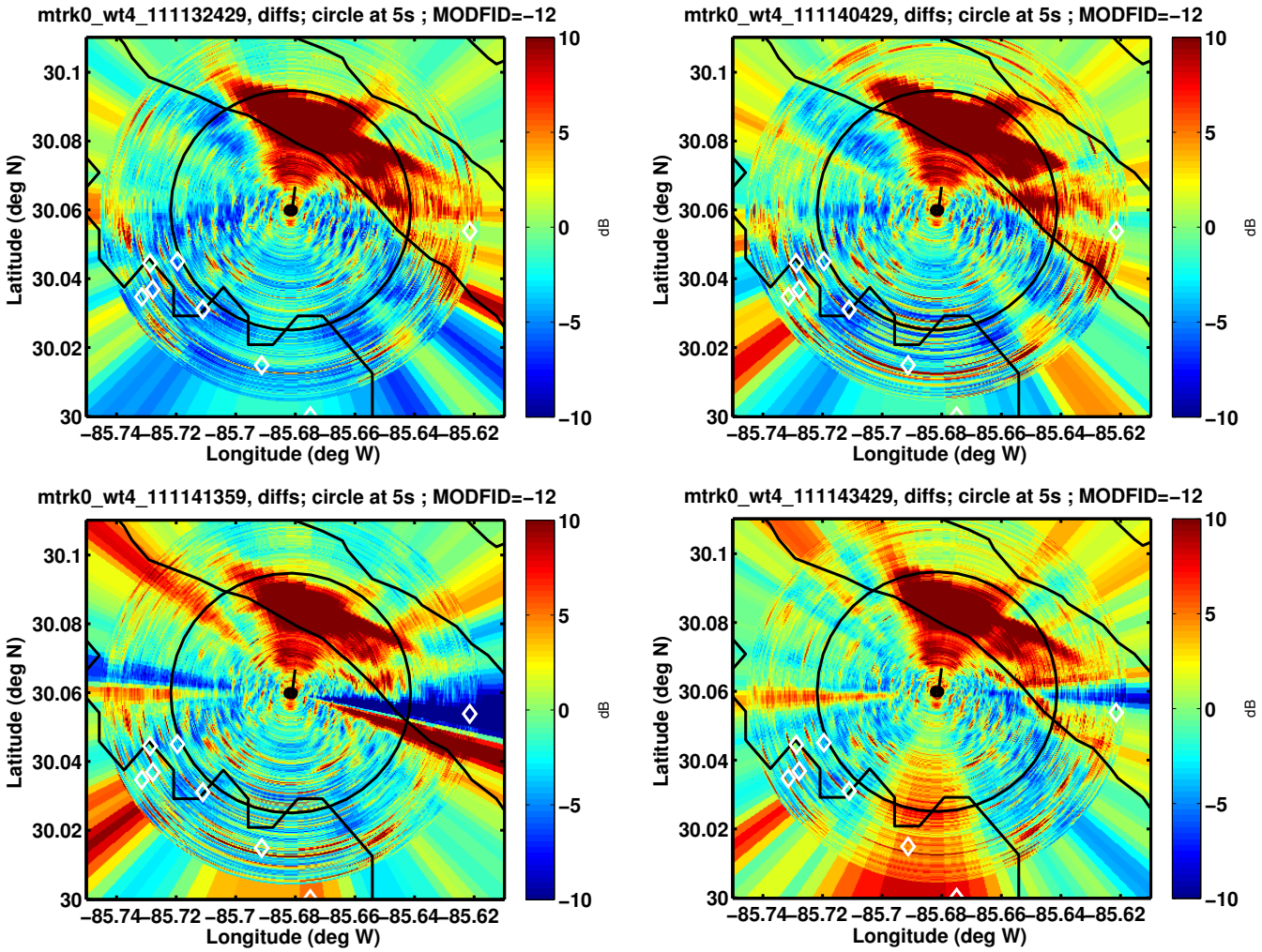

Figure 2: Plots of model-data differences for 4 pulses; model uses flat bathymetry. Note how the clutter objects are consistent ping to ping. There is some indication that very near the receiver the reverberation may be correlated with the bathymetry and sand dunes.

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.)

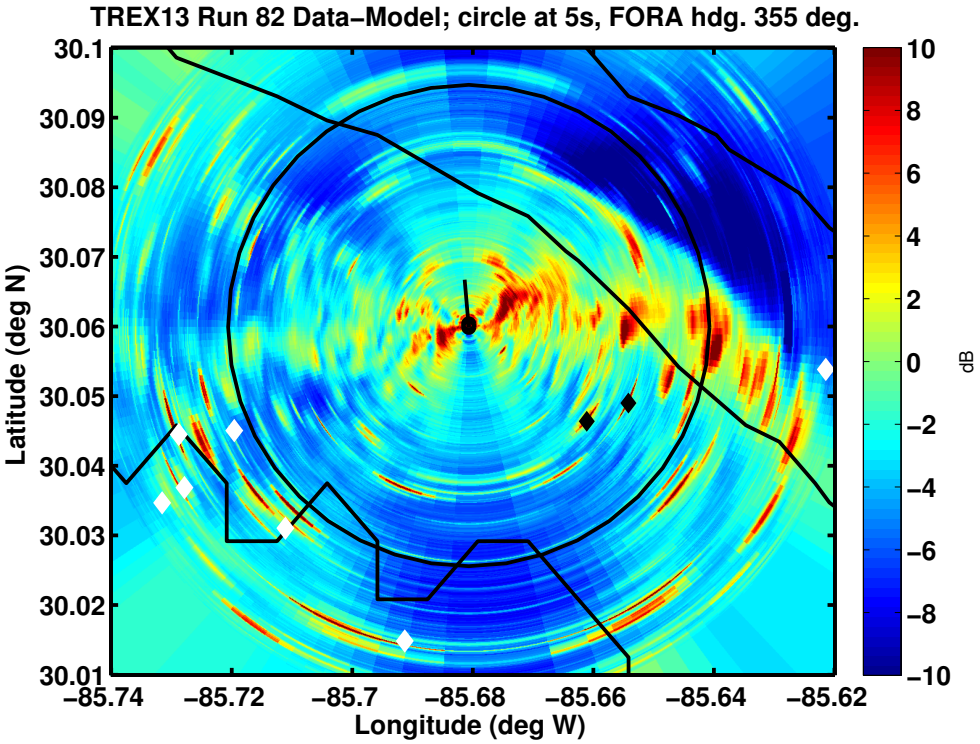

Figure 4: Polar plot of TREX13 model-data differences. Some previously-identified wrecks are denoted by the white diamonds. The black diamonds show the MPL vertical array, and the DRDC passive acoustic target.

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.

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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]