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# Measurements and Analysis of Reverberation, Target Echo, and Clutter: FY11 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 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 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 JRP "Characterizing and Reducing Clutter for Broadband Active Sonar" is now complete. A proposed JRP "Modeling and Stimulation for ASW Active Sonar Trainers" for years 2011–2013 was accepted by NURC, but no resources have been yet allocated for 2011.

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]. A paper with Holland has been published [HE09], and a paper with Ainslie and Harrison has been submitted.

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. The "Weston Symposium" extended the ONR problems to the full sonar scenario, including matched filter processing, background noise, and signal-to-noise ratio [ZAS10]. 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.

Recent work by the PI has focused on range-dependent reverberation modeling and target echo calculations, and the development of a "Clutter Model". In addition, the collaboration with Holland on the modeling of sub-bottom scattering [HE09] has been extended to include range-dependence [HE11].

## WORK COMPLETED

This section summarizes some of the work completed in FY2011.

The wrap-up meeting of the JRP "Characterizing and Reducing Clutter for Broadband Active Sonar" was held at NURC in late September 2011. Immediately following it, the initial meeting for the proposed JRP "Modeling and Stimulation for ASW Active Sonar Trainers" was held. The project has been accepted for the NURC program of work for years 2011–2013, but no NURC resources have been yet allocated for 2011.

In collaboration with Michael Ainslie and Chris Harrison, a careful comparison has been made of various predictions for Problem 11 of the 2006 Reverberation Modeling Workshop – a Pekeris environment with Lambert scattering from the bottom. The modeling approaches use analytical techniques, ray theory, energy flux, and normal modes. A presentation on this has been made at the Spring 2011 meeting of the Acoustical Society of America [AEH11], and a journal manuscript was submitted.

As part of the model development for model-data comparisons, the fast shallow-water reverberation model [Ell95, Ell08] based on normal modes has been extended to a bistatic, range-dependent Clutter Model that includes target echo and feature scattering. This formulation, based on adiabatic modes, was developed in 2008 [EPHY08] and example calculations for a flat bottom environment were done using Matlab. In 2010 the model was converted to Fortran 95, and extended to handle range-dependent bathymetry and scattering. Like the fast flat-bottom 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 describing the model appeared in Canadian Acoustics in 2010 [EP10], and further enhancements to it were made in 2011. Range-dependent predictions were compared with towed array clutter data from the Malta Plateau, and presented as an invited paper [EP11] at the 2011 Underwater Acoustic Measurements Conference. This comparison is illustrated in the "Results" section below.

A very useful feature of the Clutter Model formulation is that the computational engine 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 [BKTE10] was implemented on a Windows system in 2010, and extended to Unix systems in 2011.

Though the Clutter Model is computationally efficient, determining the limits of its adiabatic mode approach is an important research question. In 2011 the PI produced predictions [Ell11] for some range-dependent problems from the Reverberation Modeling Workshop and the Weston Symposium on Validation of Sonar Performance Assessment Tools. To facilitate this, the PI collaborated with John Preston in extending his Matlab/ORCA reverberation model [PE09] to handle range dependent environments [PE11]. Examples of these predictions are illustrated in the "Results Section" below. These seem to be the first range-dependent predictions published, and give a starting point for more accurate solutions.

Even with a smooth bottom, acoustic clutter in the water column can be generated by subbottom effects. Collaboration with Holland has shown that even slowly-varying sediment layers can lead to a large target like response. To facilitate this, the adiabatic mode model was applied to environments with a range-dependent subbottom, and predictions compared with energy flux solutions. A manuscript is in progress, and a presentation will be made at the Fall 2011 meeting of the Acoustical Society of America [HE11].

## RESULTS

This section illustrates a few results from the activities mentioned in the previous section.

### *Comparison with towed array data from the Malta Plateau*

Results from the Clutter Model were compared with towed array data from the Boundary 2004 experiment on the Malta Plateau. Figure 1 shows a polar plot of reverberation data received on the NURC towed array. The array has 84 triplet elements with a design frequency of 1800 Hz for sound speed 1512 m/s; here the 90-m SUS data in a 50 Hz band centered at 630 Hz are processed as a linear array (with left-right ambiguity). The measurement and processing procedure is similar to that described in Preston and Ellis [EP09]. For display, the time series is mapped into range and the beams are mapped into azimuth to form a polar plot, which is overlaid over the bathymetry shown with contours at 10 m intervals. The geometry is essentially monostatic, with the NATO vessel R/V Alliance towing the array on a near southerly heading of 176°. The black ellipse (circle) marks the 30 s time line. From the plot we see there is high reverberation at short times, high scattering from the Ragusa ridge to the east, and high ambient noise on several beams, particularly near endfire.

Figure 2 shows the corresponding model predictions. The normal modes were calculated at the centre frequency of 630 Hz at each grid point, using the water depth at the grid point, and a downward sound speed profile (1520 m/s at the surface and 1512 m/s at the bottom, corresponding to the measured one). The bottom was a uniform half-space with sound speed 1643 m/s, relative density 1.64, attenuation 0.7 dB/m-kHz, and Lambert's rule scattering of $-37$ dB (all obtained from a manual fit [PEG05] to previous data at a nearby site). For the calculation here, the Lambert coefficient was arbitrarily enhanced by 10 dB near the Ragusa Ridge, to account for the higher scattering expected from the rough region. Predictions on each of the 85 beams were made to a time of 36 s. For each beam the calculations were performed using 46 radials from the receiver (every 5° in the eastern quadrant and 10° elsewhere), with effective beam patterns on each radial [EP09]; the effect of the conical beams and any

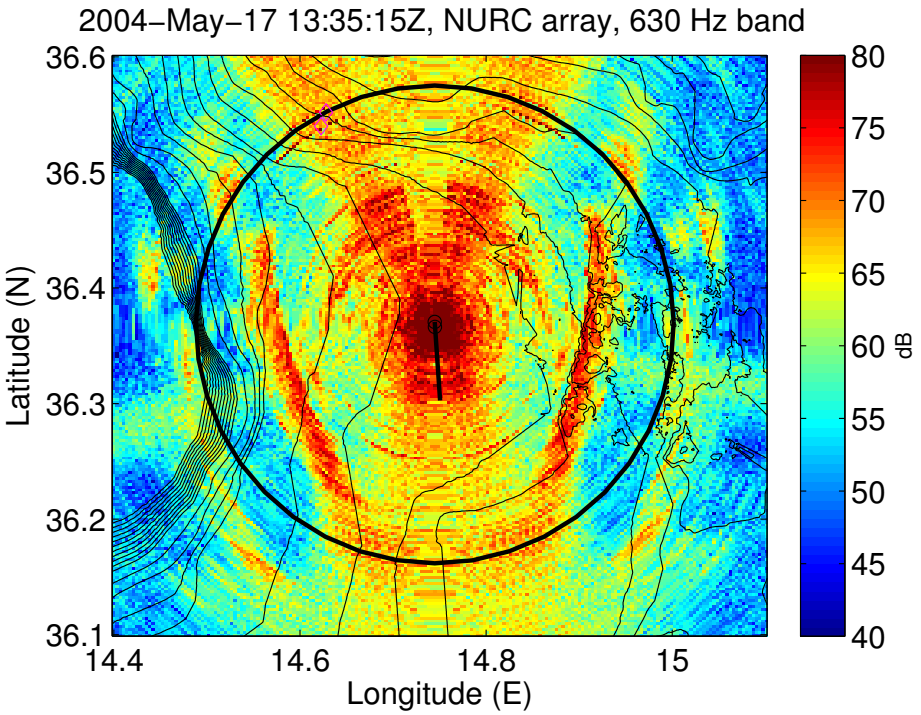


***Figure 1: Polar plot of towed array data from the Malta Plateau.***

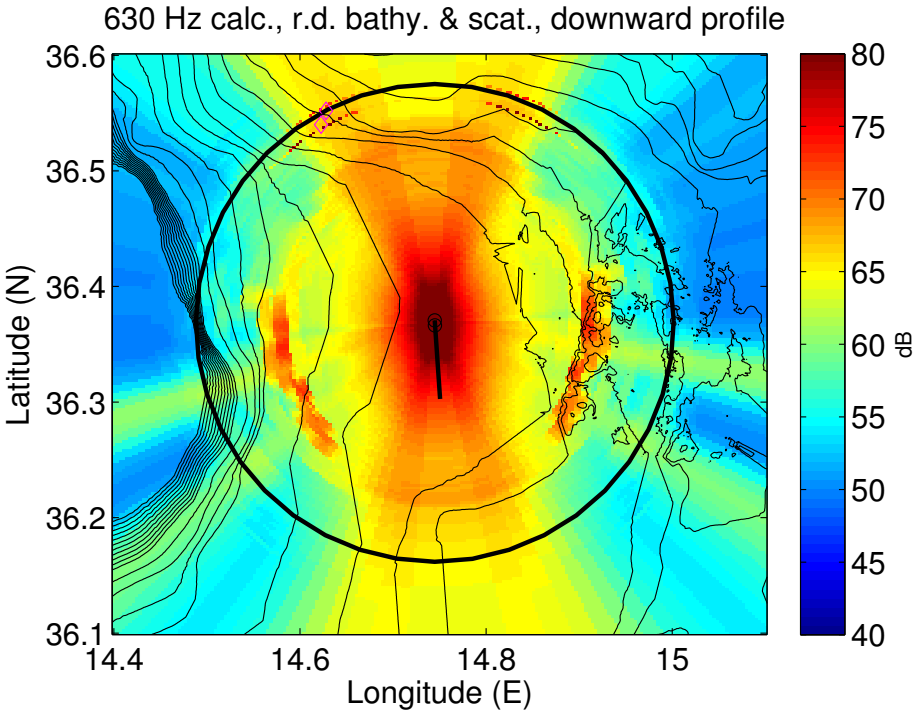


***Figure 2: Model prediction corresponding to data in Fig. 1.***

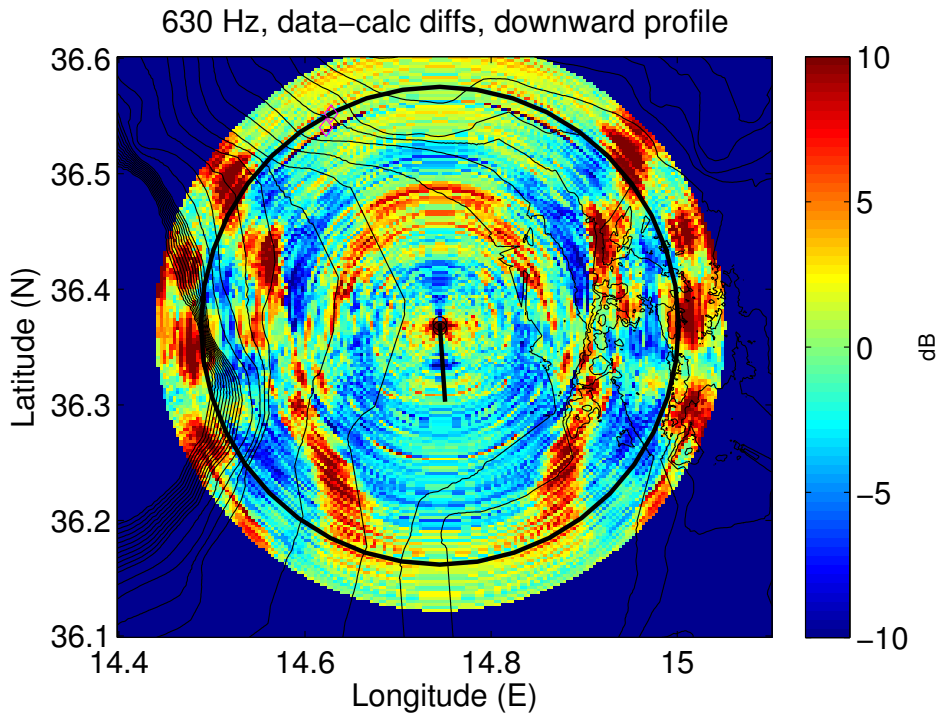


***Figure 3: Model-data differences from Figs. 1 and 2.***

sidelobes is included in the calculations. The modeled ambient noise on each beam was obtained from a sample of the measured beam data about 80 s after the main arrival. The calculation captures many of the features evident in the data. The enhanced scattering from the Ragusa Ridge shows up clearly in the predictions. Note that the reverberation has dropped below the ambient noise after about 20 s, and the noisy beams show up as radials evident near endfire and around 14° and 34° forward of broadside. The Campo Vega oil drilling platform and tender near 36.54°N 14.63°E are included as clutter objects. The computations, using the `gfortran` compiler (unoptimized), took about 50 s using only one of the processors on a 2.66 GHz MacBook Pro. This includes mode calculations (50 modes on average at each of the 2601 grid points), and calculations of reverberation and target echo at 200 time points on each of 85 beams. The model produces quite realistic results and is computationally efficient, so is being adapted for into the System Test Bed as a potential operator tool.

Given the reasonably coarse inputs, the agreement between the model predictions and data is satisfactory. However, we need to assess where improvements could be made. Figure 3 shows the model-data differences. The model is generally in good agreement with the data – within a few dB at short times where the bathymetry is quite flat. Our crude, but reasonable, scattering enhancement along the Ragusa Ridge eliminated a large part of the differences. However, the predictions are not sufficiently capturing the effect of the range-dependent bathymetry; it needs to be determined if this is due to the coarse bathymetry or if the adiabatic method needs improving.

***Adiabatic mode predictions for an upslope environment***

Adiabatic mode predictions were made [Ell11] for some range-dependent test problems from the Reverberation Modeling Workshop and the Sonar Performance Assessment Tools workshop. Here an example is shown for Problem IV.1 [ZAS10] using a variant of the Clutter Model, called `r2d3`.

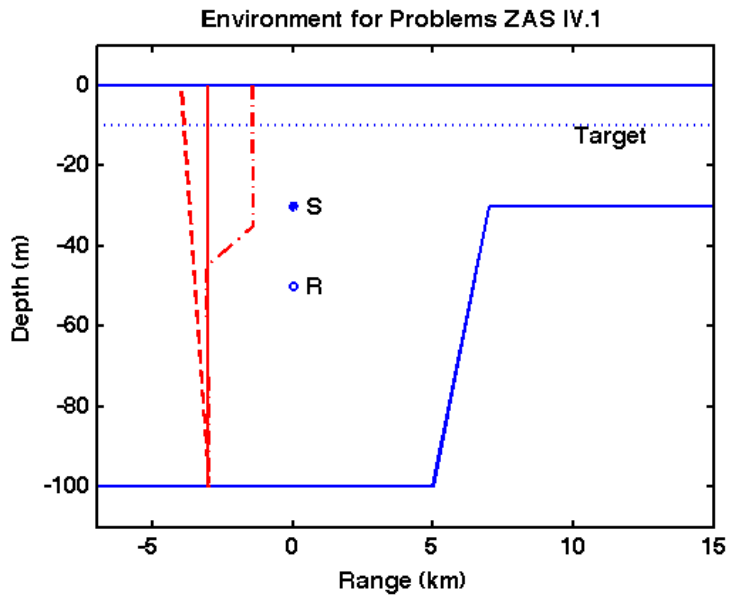


***Figure 4: Environment and geometries (in blue) for Problems IV.1; the source is indicated by S, the receiver by R, and the target depth by the dotted line. The shapes (in red) of the three sound speed profiles (winter [dashed], isovelocity [solid] and summer [dot-dash]) are shown.***

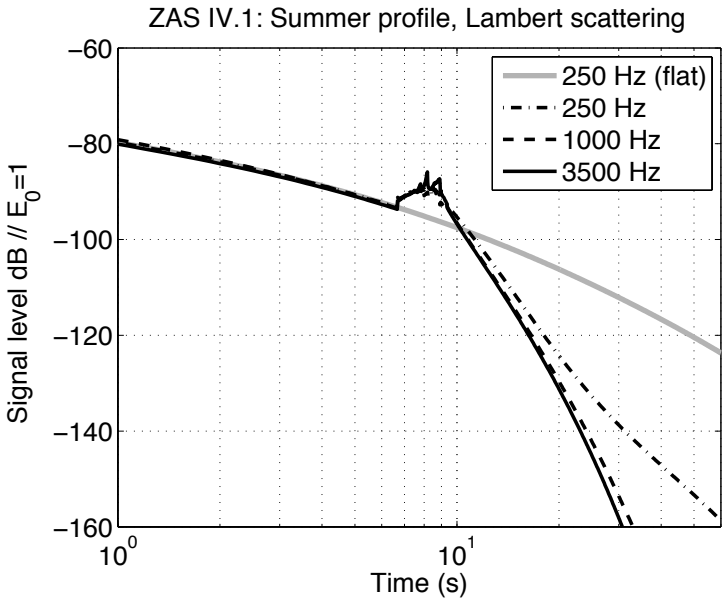


***Figure 5: Comparison of predictions at 3 frequencies using the r2d3 adiabatic mode model.***

Figure 4 illustrates the environment, which is flat at 100 m depth to 5 km, has a slope of 2.00° from 5–7 km, and continues flat at 30 m to 45 km. There can be one of three sound speed profiles: isovelocity (1500 m/s), winter (sound speed 1490 m/s at the surface, with linear gradient to 1500 m/s at the bottom); and summer (sound speeds of 1515.3, 1515.7, 1499.1, and 1500 m/s at depths of 0, 35, 45, and 100 m respectively). There are no horizontal gradients, so for the summer and winter profiles the sound speed at the bottom is not exactly 1500 m/s at the shallower depths. The bottom is a fluid halfspace, with density ratio 2.0, sound speed 1700 m/s, attenuation 0.5 dB/wavelength; the bottom scattering is Lambert's rule with −27 dB coefficient; the volume absorption in the water was assumed to be zero; the bottom loss was the Rayleigh reflection coefficient with no additional reflection loss from the scattering. An omnidirectional source of unit energy is at 30 m depth and the receiver is at 50 m, both at 0 range; a 10 dB omnidirectional point target is at depth 10 m out to 45 km. Problem IV.1 specifies the environment to be a wedge, and the receiver at 50 m depth to be a horizontal line array oriented "into the page", so that one side of the broadside beam looks directly up slope, and the other in the opposite direction. We model it as an omnidirectional receiver in an axisymmetric "bowl"; the correction for the broadside beam in the wedge would be very close to 20 dB. The UAM 2011 paper [Ell11] shows target echo and reverberation calculations for several frequencies and profiles. Figure 5 here shows reverberation at 3 frequencies for the summer profile. The grey curve shows the flat bottom case – at 250 Hz, but the other frequencies are similar. For the upslope problem, in the flat region, to 5 km (about 6.7 s), there is very little frequency dependence. The reverberation then jumps up due to the 2° bottom slope, and continues to increase as the water depth decreases. At 7 km (about 9.3 s) the reverberation drops as the bottom flattens out, and the reverberation falls off faster than the flat bottom case due to increased bottom interaction in the shallower water; the higher frequencies are affected more than in the 250 Hz case.

Preston extended his Matlab/ORCA model [PE09] to include range dependence with adiabatic modes [PE11]. His model uses the true wedge environment, the Reverberation Modeling Workshop pulse, and an ideal 2° horizontal beam pattern pointed upslope. Adjusting his result by 43 dB, Fig. 6 compares the predictions at 250 Hz for the isovelocity environment at 250 Hz for the PI's `r2d3` model and Preston's `newnoname` model [PE11] . The agreement is seen to be extremely good between the two implementations. The adiabatic method still needs to be tested against more accurate methods, such as coupled modes.

## 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. 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.

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

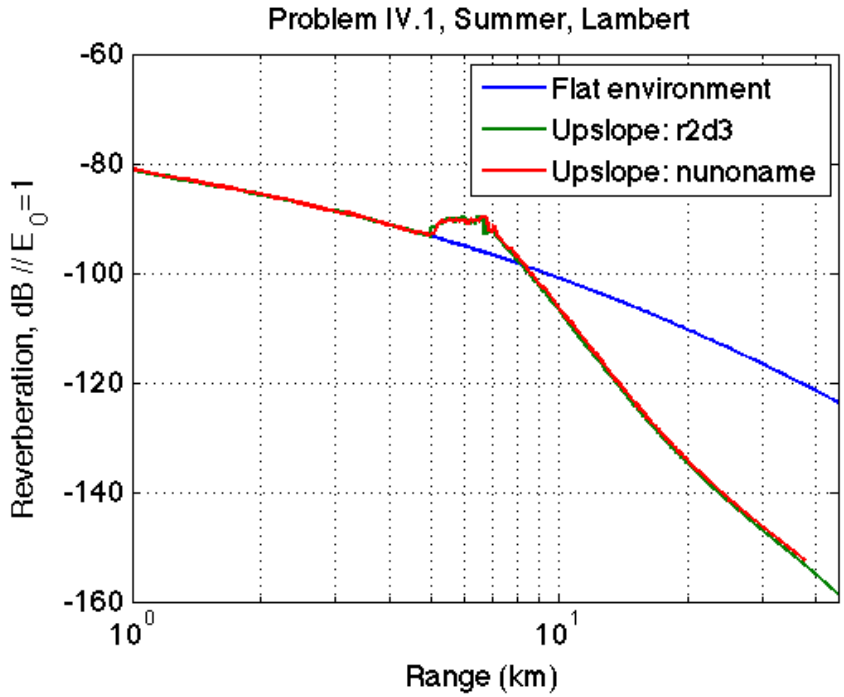


***Figure 6: Comparison of predictions at 250 Hz for Problem IV.1 with the summer profile and Lambert bottom scattering. The blue curve is the flat environment with model r2d3; the green curve is the upslope environment with model r2d3. The red curve is the upslope environment using model nunoname; it almost obscures the green curve, showing excellent agreement between the two models.***

behind the unidentified clutter on a display. These unidentified features would then be investigated by other techniques to try to determine their nature.

## 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 naval exercises including four Submarine Commander Courses (SCC) between 2008 and 2010. Small research contracts for this implementation were let in 2009, 2010, and 2011. A standalone version [BKTE10] with public domain databases and a Java GUI was developed by Brooke Numerical Systems in 2010. It is presently being extended, and the hope is to be able to integrate the Clutter Model as a Tactical Tool in the System Test Bed.

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

The 2010 David Weston Sonar Performance Assessment Symposium held in Cambridge, UK, had number of scenarios based on the ONR Reverberation Modeling Workshop problems, extended to the complete sonar problem. The driving force behind the sonar modeling is the Low Frequency Active Sonar program of TNO and the Royal Netherlands Navy.

## RELATED PROJECTS

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 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.

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- 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. [published]
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