# Studies on Sonar Clutter and Reverberation

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## LONG-TERM GOALS

The long-term goals of this effort are to:

- Assess capability of directional arrays for inversion and reverberation studies

- Characterize acoustic clutter in a manner that will lead to its mitigation

- Improve geo-acoustic parameter extraction from reverberation data

- Construct suitable high fidelity reverberation and scattering models for model/data comparison and inversion

## OBJECTIVES

The objectives of this effort are to:

- Continue validation and improvement efforts on a new reverberation model and investigate physics based clutter modeling.

- Use and continue to collect triplet array data from Five Octave Research Array (FORA) and the NURC arrays, conduct cross frequency correlation studies of scattering features to assess the utility of this technology for reverberation and clutter analysis both in the triplet frequency band (above ~600 Hz) and at lower frequencies.

- Continue work on the automated geo-acoustic parameter extraction technique using reverberation data.

- Operate, maintain and improve FORA hardware and data acquisition systems. Help plan and participate in ocean experiments in support of sea floor scattering, sonar clutter studies and ocean reverberation experiments.

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## APPROACH

A 4-year Joint Research Program (JRP) with NURC, ARL-PSU, NRL, and DRDC Atlantic, of Canada has just ended. It was called Characterizing and Reducing Clutter in Broadband Active Sonar. Experiments were being designed to support the JRP (the Principal Investigator (PI) is a member of this JRP). A recent experimental effort called CLUTTER07 took place near the Malta Plateau area in May of 2007 and then a follow-on, CLUTTER09, occurred in May 2009. They were focused on the physics-based and the statistical characterizations of acoustic clutter for lower frequency sonars. The FORA was one of two primary receivers for the CLUTTER07 experiment as well as for the BASE07 sea trial that immediately followed it.

The triplet array section at the head of the FORA offers an improved way to study reverberation and scattering in shallow water. Some FORA triplet data was collected in the 2006 Gulf of Maine experiment near Georges Bank, and a much more extensive set was taken in the 2007 CLUTTER07 and BASE07 experiments on the Malta Plateau. In addition, much data has been taken using the NURC array in the same 2007 experiments and in the CLUTTER09 and Boundary 2004 [1] experiments on the Malta Plateau. These data are serving to test and improve the beamforming algorithms and data processing tools needed to better understand reverberation and scattering from towed arrays. The NATO Undersea Research Centre has shown examples of left-right rejections in excess of 15 dB on its triplet array (NURC report SR-329A by D. Hughes, [2]). The PI has verified that similar performance was observed using FORA. Studies on wider band beamforming algorithms are a focus of analysis on the 2007 data sets. It well known that often the same reverberation features can be observed over a wide range of frequencies. Objectives for this task also involve correlating the high frequency unambiguous feature information from the triplet data with the lower frequency bearing ambiguous information from line arrays and defining the circumstances under which good cross-frequency correlations exist.

In the past the towed array based inversion algorithms developed by the PI [3] used bearing ambiguous diffuse reverberation data. So results mapped extracted geo-acoustic parameters only in a spatially averaged sense when reverberation was anisotropic. Assessment is continuing on new inversion work using triplet reverberation data with unambiguous bearing information.

A new faster and simpler range-dependent reverberation model is in ongoing development (together with Dale Ellis of DRDC who is working jointly with the PI) and will serve as the forward model engine for the simulated annealing based inversion scheme already in use. Refinements to this model are continuing under this effort (see below for details). Examples from the new reverberation model were presented at both the 2006 and 2008 ONR Reverberation Modeling Workshops in Austin, TX and in more detail at the 2007 Underwater Acoustics Measurements (UAM) Conference in Crete, at the NURC 2008 clutter symposium and most recently at the UAM conference in Kos, Greece in 2011. The PI continues to work with the modeling community to support model comparisons that highlight strengths and weaknesses of various approaches [A1-A5].

## WORK COMPLETED

A recent paper by the PI on triplet data analysis presented some directional characteristics of observed clutter and reverberation using triplet arrays [4]. He showed there is usable left right discrimination down to ~600 Hz using the NURC triplet array. Also shown was that the Hughes triplet beamforming algorithm has an upper frequency limitation. In that paper the PI also derived the normalization terms

needed to provide calibrated levels out of triplet arrays. More recently the PI has been studying how to improve the Hughes algorithm and has determined that simply expanding the optimum weights term to second order rather than first order destroys the simple linear dependence of the optimum weights on the sines of the roll angles. After conversations with K. LePage at NURC the PI has concluded that the closed form solution for the weights should be used as one way to improve performance. This requires a recoding of the algorithm so work is proceeding on that and the revalidation of the new beamformer. An entirely different technique by Ivars Kirstein at NUWC is also being explored.

Together with D. Ellis, the PI published two invited journal articles on our Rapid Environmental Assessment (REA) techniques using reverberation. The articles are a compendium of our joint work from 1996 to 2004 and so we felt it was important to document our efforts in a peer reviewed journal [5,6].

A range dependent normal mode based reverberation model (in collaboration with D. Ellis of DRDC) has been developed. Westwood's ORCA [7] is used to generate the eigenvalues and eigenfunctions for an environment and then modifications to Ellis' techniques [8] have been used to build the reverberation model using MATLAB. Results have been presented at many conferences (e.g. [9–11]). One version of the code added the time spread and dispersion corrections used by Ellis [8] to the model. Last year work was done to improve the short time reverberation estimates by adding leaky modes from ORCA to the algorithm. This year the adiabatic normal mode formulation to handle weakly range dependent problems has been added. Most recently, the ability to model target echo and/or clutter features has been added to help study the physics of clutter[A1, A3, A4].

The PI has also spent some of effort in overseeing the 'care and feeding' of the ONR FORA at Penn State and preparation for the 2012 (GULFEX12) pilot experiment off Panama City, FL on reverberation with APL-UW. Some longer range experiment planning efforts using FORA for ONR are discussed in the next section. The PI also helped tie up preliminary results from the very successful LRAC10 experiment [A5].

**RESULTS**

Using the above-mentioned Matlab and ORCA based reverberation model, some sample results are presented below, either inspired by or from the first Reverberation Modeling Workshop (RMW I) of Nov. 2006 [12,13] (sponsors: U.S. Navy PEO C4I, PMW 120 (funded by the Oceanographer of the Navy) and ONR). In previous work, the range independent version of this model was used to provide solutions to parts of 10 problems submitted to the Workshop [10] and these solutions were well matched to the many other models of the workshop. A baseline was Problem 11 that was a monostatic 3-D problem with the seafloor modeled as a simple fluid half space (density = 2 $g/cm^3$, compressional speed = 1700 m/s, attenuation = 0.5 dB/wavelength) and a Lambert's Rule scattering kernel assumption with a scattering strength of -27 dB. The pulse was specified by the RMW workshop to be an omni-directional Gaussian pulse with an energy level of -17.26 dB at 250 Hz. The problem was range independent in 100 m of water with a source depth of 30 m and three receiver depths of 10, 50 and 90 m. Computations were requested for 250, 1000 and 3500 Hz.

In the following examples, Lambert's Rule with $\mu$=-27 dB is used as the scattering kernel and the source level is the same as in Prob. 11 above. Note that results for times earlier than 1 s are not plotted since they are suspect as 3-D corrections and other nearfield physics have not been applied. The first

plot for this new model shows predictions at 250 Hz for a wedge in the RMW I problem 17 environment (which is flat, 200 m deep everywhere in the negative y-direction and has the same bottom as Problem 11). The wedge has no offset in the y-direction going from 200 m to 0 m in the space of 7.4 km and is infinitely long in the x direction. The prediction is for a 1° wide cookie-cutter receiver beam looking directly upslope (slope = 1.55°). Predictions are for a receiver depth of 50 m. Also shown is a solution from an independent model written earlier by Ellis [14]. The agreement between the two models seems to be quite good. The next example is from the 2010 David Weston Sonar Performance Assessment Symposium. Figure 2 is the comparison prediction at 250 Hz of both reverberation and echo level vs. time for Problem IV.1 from Zampoli et al. [15] between the Ellis model using a winter profile and this model also using a winter profile, for a 1° beam looking upslope with a wedge offset in the y-direction of 5 km and having a 2° slope. The agreement between the two models also seems to be quite good.

Regarding the FORA, this year's work has centered around preparing for a new DURIP funded refurbishment and participating in planning efforts to support ONR's three major experiment efforts scheduled for FY 2013, 2015 and 2017 with FORA. Also, planning for a pilot experiment to support the 2013 reverberation field experiment has begun in earnest with APL-UW.

**IMPACT/APPLICATIONS**

A better understanding of sonar clutter is key to improving sonar performance in shallow water. The new FORA and NURC triplet arrays are exciting tools for ocean acoustic researchers. A wide area-averaged bottom parameter estimation technique such as described above and that utilizes directional reverberation measurements could provide a quick way to estimate bottom parameters and hence give improved sonar performance estimates. Improvements made to the FORA acquisition system recently have made one-way travel time estimates accurate to within a ms. Time tagging and error logging the data blocks has made it possible to find data dropouts quickly for the first time with FORA. Significant improvements have been made by the PI to his normal-mode-based reverberation and clutter model.

The CLUTTER09, CLUTTER07 and BASE07 experiments on the Malta Plateau have produced a large quantity of high quality data that will help ONR researchers to understand and eventually mitigate sonar clutter.

**TRANSITIONS**

Inversion techniques similar to those described above have been applied to select data from recent Harsh Environment Program (HEP) experiments as part of ONR 6.2 efforts led by Dr. R. Wayland in support of the IEER program at NAWC. In addition, the above inversion concepts and reverberation models have been incorporated into the Tactical Operations Center (TOC), the Environmentally Assisted Processor (EAP) and also the PADs program at ONR.

**RELATED PROJECTS**

This work 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.

A long term collaboration with D. Ellis of DRDC-Atlantic in Canada continues and has helped the PI greatly with his own work.
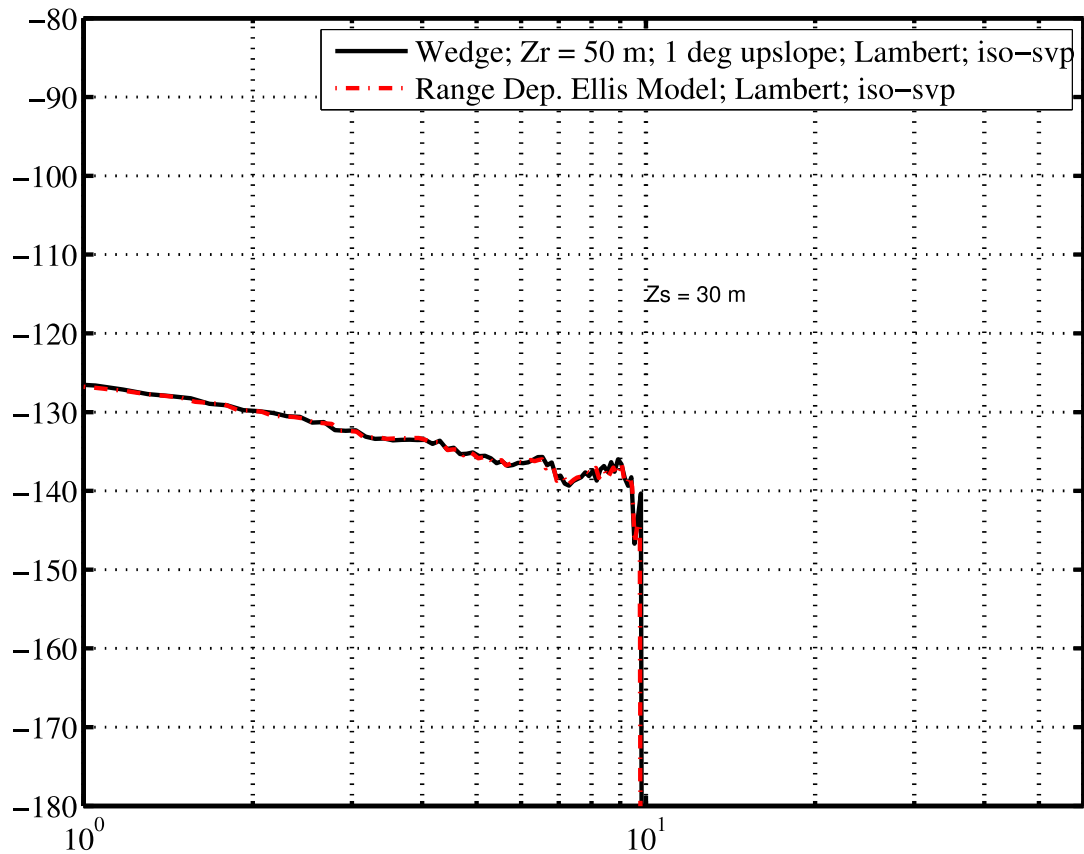


*Fig.1. A comparison of the PI's model with Ellis' R2D3 model of reverberation vs. time for RMW I, Problem 17; for a 1° beam upslope and 50 m receiver at 250 Hz. (Source depth 30 m).*
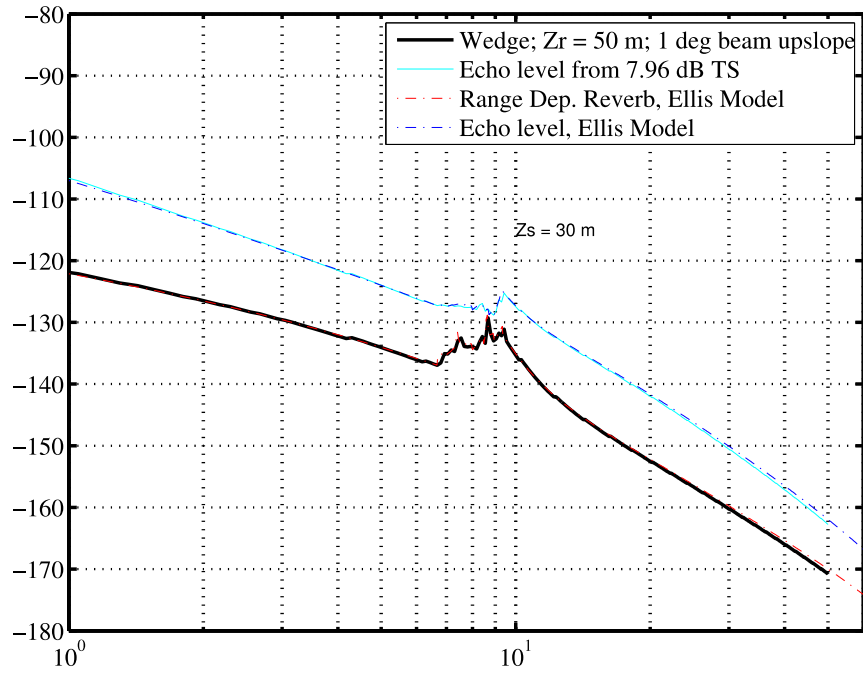
*Fig.2 Reverberation vs. time and echo level vs. time at 250 Hz; comparison between Ellis' R2D3 model and this model using a winter profile and a 1° beam upslope. Defined as Problem IV.1 from Zampolli et al. 2010 with bathymetry containing an offset wedge having a 2° slope. Source depth 30 m, receiver depth 50 m.*

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