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
- Operate and maintain the Five Octave Research Array (FORA) for ONR-OA

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 FORA and the CMRE 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.

APPROACH

A 4-year Joint Research Program (JRP) with NURC, ARL-PSU, NRL, and DRDC Atlantic, of Canada was called Characterizing and Reducing Clutter in Broadband Active Sonar. Experiments were designed to support the JRP (the Principal Investigator (PI) is a member of this JRP). An experimental part of this 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 NATO Undersea Research Centre (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 NURC has shown examples of left-right rejections in excess of 15 dB on its triplet array (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. Recently, more triplet data has been collected during the very shallow water GULFEX12 Experiment and early results are very promising (see below).

In the past the towed array based inversion algorithms developed by the PI [3] used bearing ambiguous diffuse reverberation data. So results extracted geo-acoustic parameters only in a spatially averaged sense when reverberation was anisotropic (see [5],[6]). 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 more recently at the UAM conference in Kos, Greece in 2011 and the ECUA conference in 2012 [A1, A2]. The PI continues to work with the modeling community to support model comparisons that highlight strengths and weaknesses of various approaches.

WORK COMPLETED

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. Recent work was done to improve the short time reverberation estimates by adding leaky modes from ORCA to the algorithm. The adiabatic normal mode formulation to handle weakly range dependent problems has also been added. Recently, the ability to model target echo and/or clutter features has been added to help study the physics of clutter [17,19,20].

A 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.

The PI has also spent some of effort in overseeing the DURIP funded upgrades to the ONR FORA at Penn State and preparation and participation in 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.

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] (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 [22] to parts of 10 problems submitted to the Workshop and these solutions were well matched to the many other models of the workshop. A baseline was Problem 11 which was a monostatic problem with the seafloor modelled 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 with a scattering strength of -27 dB. The pulse is specified 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 to be for 250, 1000 and 3500 Hz.

In the first example below, Lambert's Rule with mu=-27 dB is used as the scattering kernel and the source level is the same as in Problem 11 above. Note that results for times earlier than 1 s are not plotted since they are suspect close in as 3-D corrections have not been applied. The first plot for this new model shows predictions at 250 Hz for a ridge (2-D seamount) environment (which is flat, 100 m deep everywhere in the negative y-direction and has the same bottom as Problem 11). The ridge has a 5 km in the y-direction going from 100 m to 30 m in the space of 2 km, flat for 1 km and then back down to 100 m at 10 km, and is infinitely long in the x direction. The prediction is for a 1° wide cookie-cutter receiver beam looking directly upslope (slope = 2°). Predictions are for a receiver depth of 50 m. Also shown is a solution from an independent model written earlier by Ellis [14] for the original wedge problem. The agreement between the two models seems to be quite good up to 7 km as expected. The next example is inspired by the Boundary series of experiments with NURC. Figure 2 shows a data model comparison for a SUS charge: reverberation vs. time at 630 Hz in the Malta Plateau, using Lambert's Rule (mu=-37 dB) and the Boundary 2004 spring profile for a towed array broadside beam looking East (and west) going up the Ragusa Ridge. Originally the comparison was poor but where ever local slopes are greater than 1 degree the Lambert's coefficient was changed to -17 dB and the data-model comparison improves remarkably. Finally, from this years' GULFEX12 experiment off Panama City FL, a sample polar plot shows reverberation and clutter vs. location using the FORA triplet aperture. These data used a 0.1 s LFM pulse from 2500 to 3500 Hz and a source depth of 17 m, receiver depth of 16 m and water depth of 18 m. A great many clutter returns are seen in the plot in spite of the relatively benign bathymetry. The symbols in the figure show the locations of five wrecks (and bridge spans); four of those show up as clutter in the plot.

Regarding the FORA, this year's work has centered around overseeing a new DURIP funded refurbishment and participating in planning efforts to support ONR's two major experiment efforts scheduled for FY 2013 and 2015 with FORA. Also, the PI participated in GULFEX12 (run by APL-UW), the pilot experiment using the FORA. This effort is meant to prepare us for the 2013 TREX13 reverberation field experiment with APL-UW.

IMPACT/APPLICATIONS

A better understanding of sonar clutter is key to improving sonar performance in shallow water. The 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 CLUTTER07, BASE07 and CLUTTER09 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. New fixed-fixed reverberation and clutter data from the GULFX12 and TREX13 experiments will add to this understanding by removing source and receiver motion effects from the data collection.

TRANSITIONS

Work on DRDC clutter model is very relevant to the Canadian program on multistatics

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

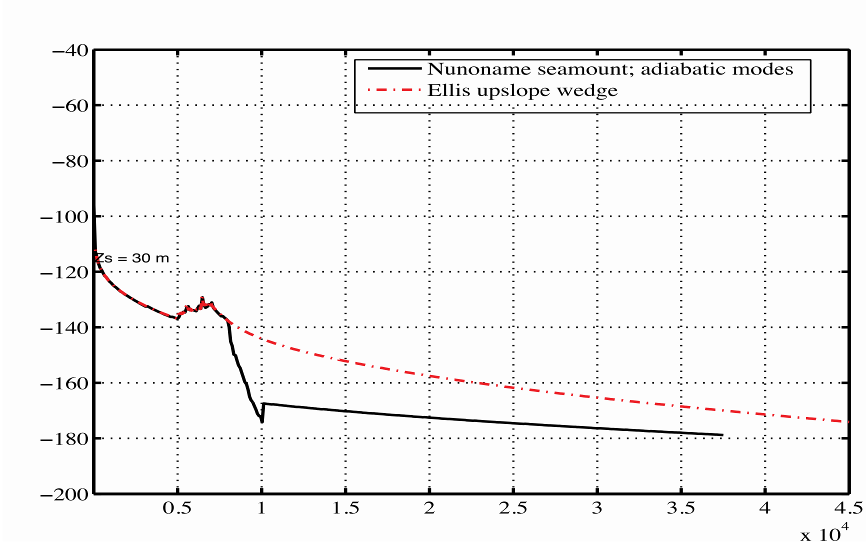

Fig. 1. A model-model comparison at 250 Hz of reverberation vs. time between Ellis' model and this model, for an offset ridge having a 2 deg. slope (modified Problem IV.1 from Zampoli et al.) using using Lambert's rule and a winter profile and using a 1° beam and 50 m receiver

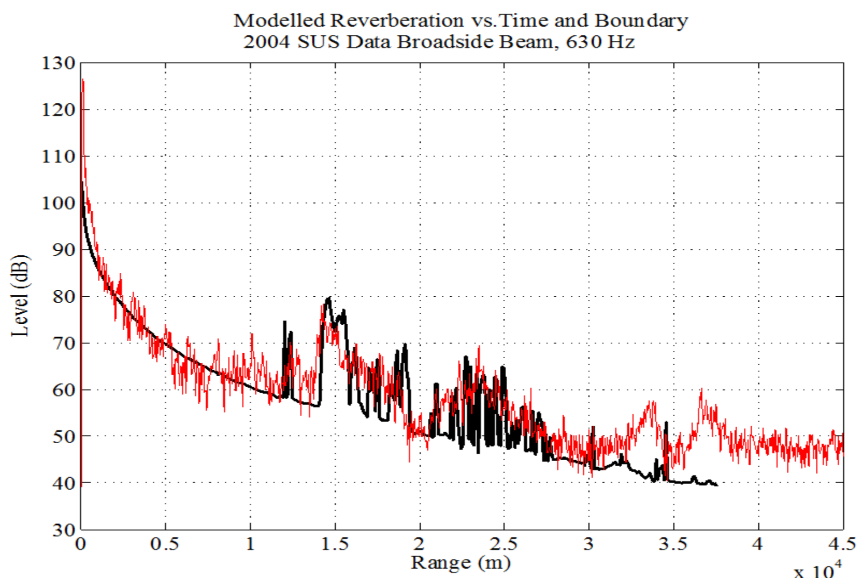

Fig. 2. Data model comparison for a SUS charge: reverberation vs. time at 630 Hz in the Malta Plateau, using Lambert's Rule (Coeff. = -37 dB) and the Boundary 2004 spring profile for a towed array broadside beam looking East (and West) going up the Ragusa Ridge. Originally the comparison was poor but whereever local slopes are greater than 1 degree the Lambert's coefficient was changed to -17 dB.

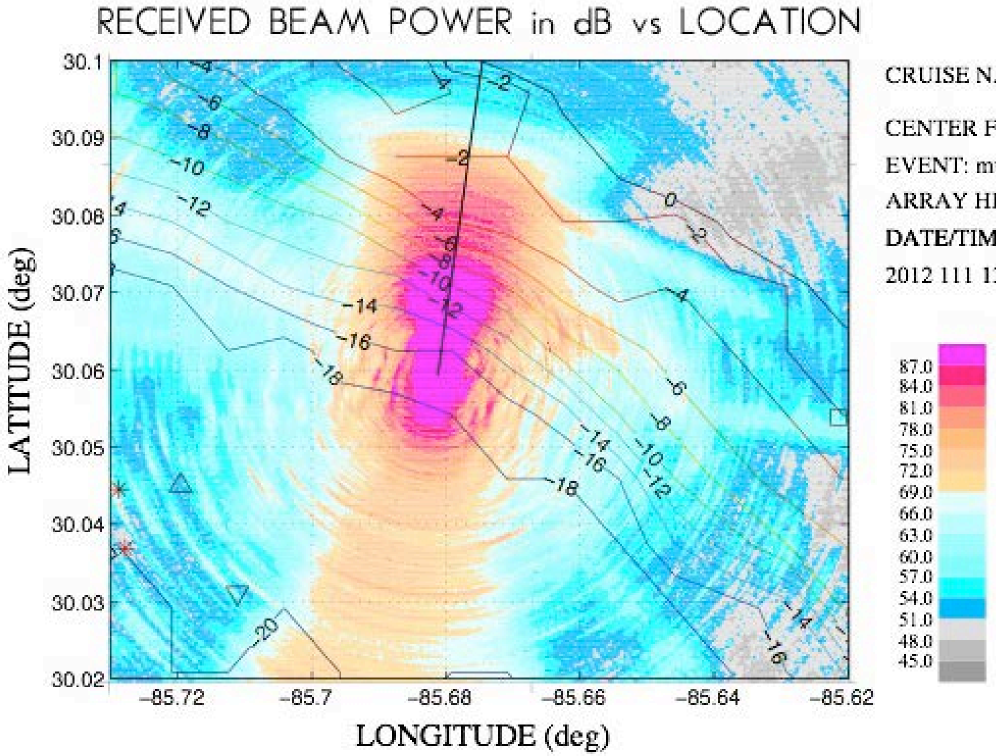

Fig. 3 Polar plot of reverberation vs. location using the FORA off Panama City, FL and a 0.1 s LFM from 2500–3500 Hz (triplet beamforming). Water depth18 m; source depth 17 m; receiver depth 18 m. Symbols show the locations of shipwrecks and other man-made sources of clutter.

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HONORS/AWARDS/PRIZES

Elected a fellow of the Acoustical Society of America in 2012.