Analysis and Modeling of Multistatic Clutter and Reverberation and Support for the FORA

John R. Preston
Applied Research Laboratory
The Pennsylvania State University
P.O. Box 30, MS3510D
State College, PA 16804
phone: (814) 863-1310 fax: (814) 863-8783 email: jrp7@arl.psu.edu

Grant Number: N00014-13-1-0029
http://www.arl.psu.edu

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

- Help plan, participate in, and analyze data from the GULFEX12 pilot and TREX13 Reverberation and Scattering Experiments and the 2014/2015 pilot and Bottom Characterization Experiments. The PI's technical objectives for the experiments are to characterize and model multistatic bottom clutter and demonstrate inverse methods on reverberation data.
- Continue improvement and validation of a new range-dependent reverberation and clutter model (a more accurate forward model for inversion) and the automated geo-acoustic inversion technique from reverberation data developed by the PI and D. Ellis of DRDC. Continue Reverberation Modeling Workshop follow-on activities.
- Use nearfield triplet data from the Five Octave Research Array (FORA) to extract bottom information for the upcoming ONR experiments and fold it into inversion schemes using reverberation data (together with C. Holland). Continue investigations of optimum triplet processing to enhance the quality of extracted clutter and reverberation data.
- Continue to investigate statistical differences between sonar clutter from the sea bottom interface and the bio-clutter masses seen in select data sets.

- Operate, maintain and improve FORA hardware and data acquisition systems. Participate in ocean experiments like the 2013 TREX13 experiment, the 2014 Bottom Characterization Pilot experiment and the main 2015 Bottom Characterization experiments, as well as other efforts as directed by ONR-OA.

APPROACH

There is a 6-year ONR OA plan for three large experiments involving many researchers and organizations. The first experimental effort was the TREX13 experiment which took place this year near Panama City. It was focused on the characterization of very shallow water reverberation and includes the PI's techniques for statistically characterizing acoustic reverberation and clutter. The triplet array section at the head of the FORA was used to give a directional look at clutter, reverberation and scattering in shallow water. In the GulfEx12 pilot experiment FORA was successfully deployed in a fixed-fixed configuration with the triplet section mounted on tripods while the RV Sharp was in a 4-point moor. In the 2014/2015 Bottom Characterization experiments, if feasible, FORA will be modified to conduct nearfield bottom reflection and scattering strength measurements in collaboration with C. Holland. The FORA would provide an alternative to using the CMRE AUV and towed array that may not be available. The FORA would also be used to make wide-area reverberation and clutter measurements together with the ARL-UT bottom mounted SWAMI array.

Relative to using reverberation data for geo-acoustic inversion, a key focus of this work will involve steering the short time cardioid beamformed data up/down to separate the vertical arrival structure on the triplet array. This will involve working with C. Holland and using the data in a similar fashion to what he does to extract layering and density estimates and possibly scattering strength estimates that are not available from reverberation data taken on conventional towed arrays.

The PI has completed an analysis of the normalization needed to provide calibrated levels out of cardioid arrays and highlighted problems at larger *ka* (J.O.E., 2007). Work on extending the frequency range of validity will continue either by trying a higher order version of the Hughes algorithm [2] or by trying some techniques being used by Groen et al., (J.O.E., 2005).

A new adiabatic range-dependent reverberation model using ORCA and MATLAB has recently been developed together with Dale Ellis of DRDC who is working with the PI (see Figure 1 below). It has been tested against Ellis' model for several problems and compared quite well with that model. A focus of the model development work will be to speed up the computations. It is expected that other refinements to this model, including further benchmarking, will continue under this effort. Part of this work would also be devoted to participating in any new ONR sponsored Reverberation Modeling Workshops and other follow-on efforts being organized by M. Ainslie of TNO.

In a related effort, the PI completed work to statistically characterize the bistatic bottom clutter and shipwreck echoes seen in the Clutter07 data sets using methods developed by D. Abraham. Results show many data segments of matched filtered amplitudes to be non-Rayleigh and will therefore lead to higher false alarms on conventional sonar systems. Recently a Rayleigh mixture model has been added to the analysis toolbox to augment the K-distribution parameterization of the data. This work will be extended to develop statistical characterizations of the reverberation data that are likely fish-dominated scattering as compared to the bottom-dominated regions to check for possible discriminants.

The ONR Five Octave Research Array (FORA) at Penn State, is operated and maintained by ARL-PSU. Work under this task includes overseeing repairs at Teledyne Instruments in Houston TX as funds are made available for that work. It includes regular maintenance and testing of the array, winch, acquisition systems and all other system components requiring attention. FORA acquisition system upgrade and software testing will be done under this task. It includes acting as point of contact for researchers asking about calibration issues, older data sets, data format problems, system specifications, array capability etc. It also includes coordination of array transportation and logistics for up to 3 experiments between Jan. 2013 and Oct. 2015. Finally, it will also include engineering coordination for any future upgrades or repairs to FORA and planning for possible follow-on arrays to the FORA.

WORK COMPLETED

This last year work centered primarily around analysis and reporting of the GULFEX12 pilot experiment results; preparation and participation in the main TREX13 experiment; FORA processing software improvements; and analysis of TREX13 results. An initial GULFEX12 paper was presented at the 2012 Kansas City meeting and a wrap up paper was written and presented at the 2013 UAC meeting in Corfu, Greece. For TREX13 several planning meetings were attended and lots of e-mail advice required since the FORA was a key element of the TREX13 experiment. The PI and his technician spent a total of 5 ½ weeks on site for the TREX13 experiment, with the PI living on R/V SHARP for 21 days. Since then a considerable effort has gone into completing an automated data processing scheme for FORA data from pulsed sources. The stream uses Linux scripts to manage Fortran, c and Matlab processing software. It takes raw data, extracts an aperture and moves it into a matrix of hydrophone vs. time. From there the data are bandshifted, bandpass filtered and decimated, then they are beamformed and matched filtered. Ancillary data like array heading and triplet roll, etc.; are combined to form the inputs necessary to produce geo-referenced polar plots of reverberation clutter and ambient noise. Each processed ping results in several intermediate files as well as spectrograms, beam (raw and matched filtered) vs. time outputs and polar plots. This suite of tools can now be made available to any future users of FORA.

The PI has also spent some of effort this year in overseeing repairs to the ONR FORA at Penn State and in processing and discussing reverberation and clutter data with APL-UW, DRDC Canada and many other organizations.

RESULTS

Since the source level used was relatively low (203 dB re 1μPa) the reverberation was not expected to be very non-Rayleigh, and indeed that is what was found. Using methods developed by Abraham [24], Fig. 1 shows a classic computation of probability of false alarm vs. threshold for the matched filter envelope reverberation data on a broadside beam (green) versus a similar plot for a Rayleigh distributed random variable (red) and that for a K-distributed random variable with shape parameter α and scale parameter λ, that best match the data using a method of moments technique (blue). Typically, shape parameters less than 10 indicate a very non-Rayleigh (heavy tailed) distribution while shape parameters larger than 20 are typically Rayleigh-like (normally distributed raw data). In this example the best fit shape parameter was 21.8 indicating a nearly Rayleigh behavior for this ping sample. A summary of the GULFEX12 findings from the FORA was:

- First successful deployment of the FORA's standalone triplet aperture (also it was mounted on tripods), in a fixed-fixed experiment.
- Up to 5 s of reverberation is observed on the FORA when using 0.1 s LFM pulses.
- Triplet beamforming shows good left/right rejection.
- Discrete clutter is seen using all four different pulses analyzed even though the bathymetry is benign away from the shoreline and almost flat.
- Preliminary statistical characterization shows beam reverberation plus clutter is nearly Rayleigh-like.

Figure 2 shows two noise power plots illustrating a mysterious nighttime noise in the 4 -5 kHz region that was observed nightly during the TREX13 experiment. The red line shows a typical daytime ambient spectrum. However, just after 8 PM local each night a loud (> 20 dB) increase in level was observed in the 4- 5 kHz band lasting until at least 4 AM local before turning off again (see example spectrum as blue line in Fig. 2). It is thought to be biologic in nature and was observed on both FORA and the R/V QUEST recordings.

Figure 3 shows a sample matched filter output for a 1 s LFM pulse from 1800–2700 Hz for a beam looking along the designated 'Reverb Track'; bearing 129° T (triplet beamforming). Also shown in red is the Gaussian smoother filter output used to estimate the incoherent reverberation levels which are usefuk for modeling comparisons.

Finally, from this years TREX13 experiment off Panama City FL, Fig. 4 is a sample polar plot shows reverberation and clutter vs. location using the FORA triplet aperture. This plot is a dB average over five pings. These data are from a 1 s LFM pulse from 1800 to 2700 Hz with 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 black angle bracket symbols in the figure show the locations of 9 potential clutter objects including wrecks and bridge spans; five of those show up as clutter in the plot.

Regarding the FORA maintenance, this year's work has centered around overseeing a repairs to FORA at Teledyne Instruments in Houston TX.

IMPACT/APPLICATIONS

A better understanding of sonar clutter is key to improving sonar performance in shallow water. The FORA triplet array is an exciting tool for ocean acoustic researchers. Improvements made to the FORA acquisition system recently have made one-way travel time estimates accurate to within a ms. For the first time with FORA, time tagging and error logging the data blocks has made it possible to find data dropouts quickly. 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 have added 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

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

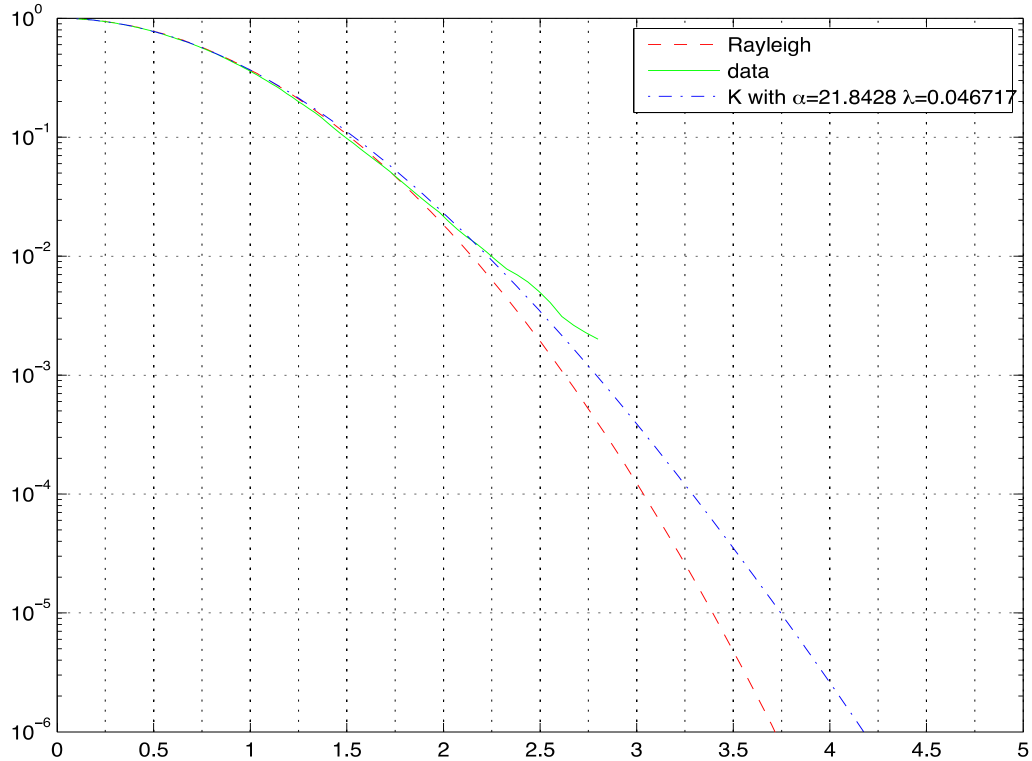

Fig. 1 Plot of beam time series statistics from GULFEX12 for a triplet broadside beam compared to Rayleigh and K-distributed statistics, using a 0.1~s LFM from 2500--3500 Hz.

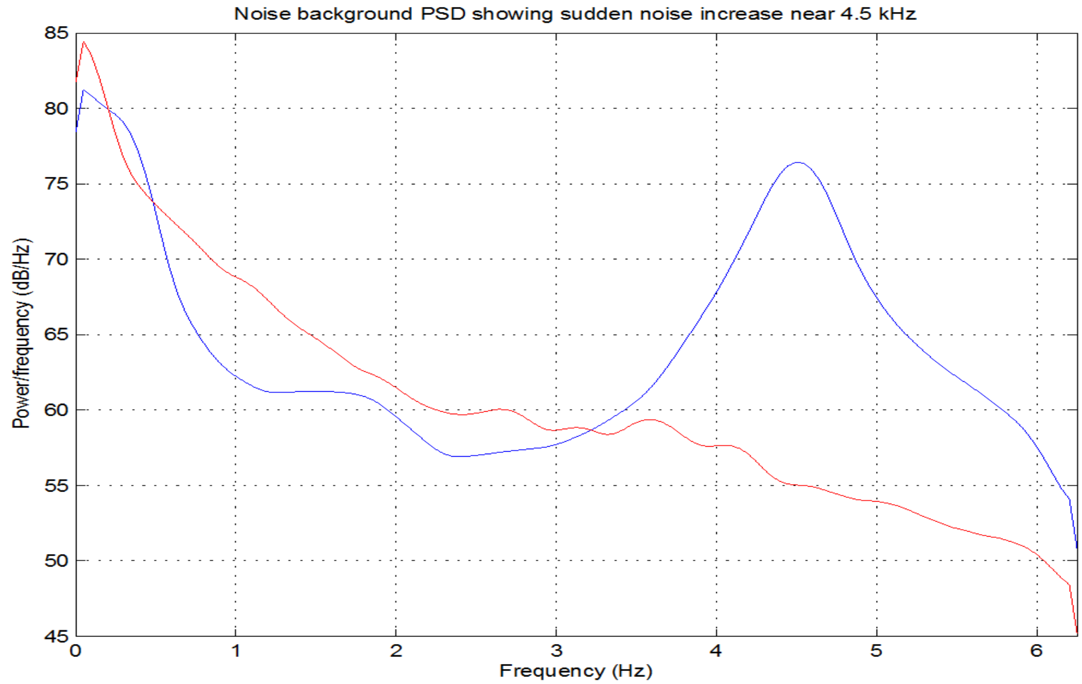

Fig. 2 Noise power plots illustrating a mysterious nighttime noise in the 4 -5 kHz region that was observed nightly during the TREX13 experiment (blue line). The red line shows a typical daytime ambient spectrum.

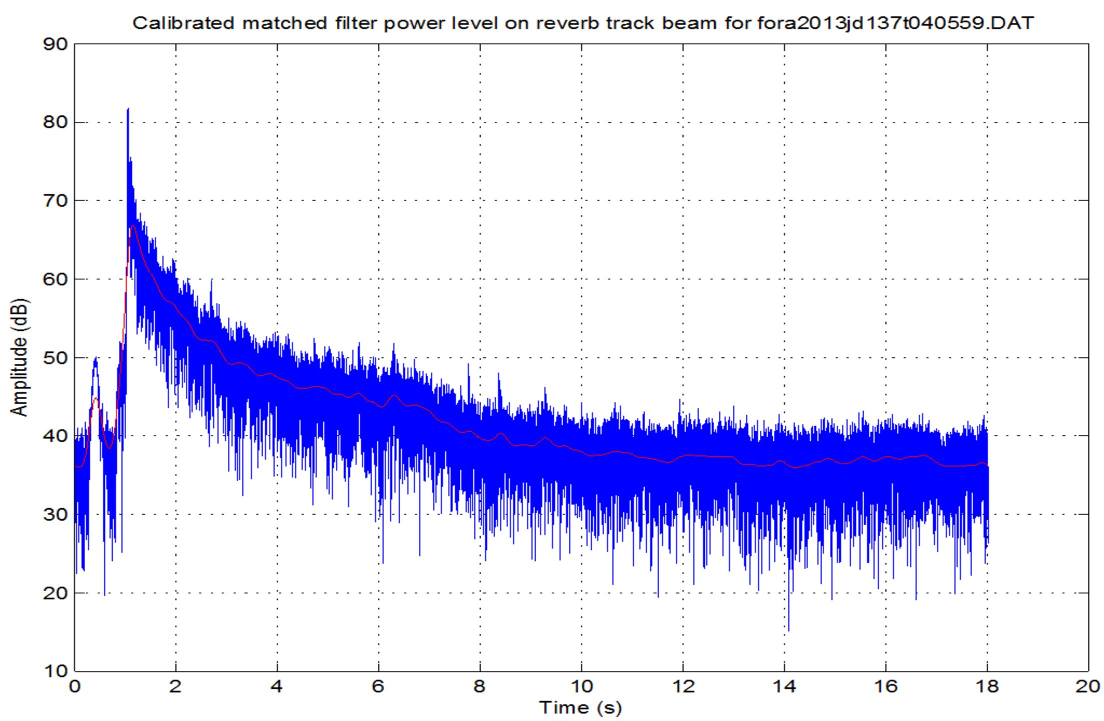

Fig. 3. Sample matched filter output from TREX13 for a 1 s LFM pulse from 1800–2700 Hz for a beam looking along the designated 'Reverb Track'; bearing 129° T (triplet beamforming). Also shown in red is the Gaussian smoother filter output used to estimate the incoherent reverberation levels which are more useful for modeling comparisons.

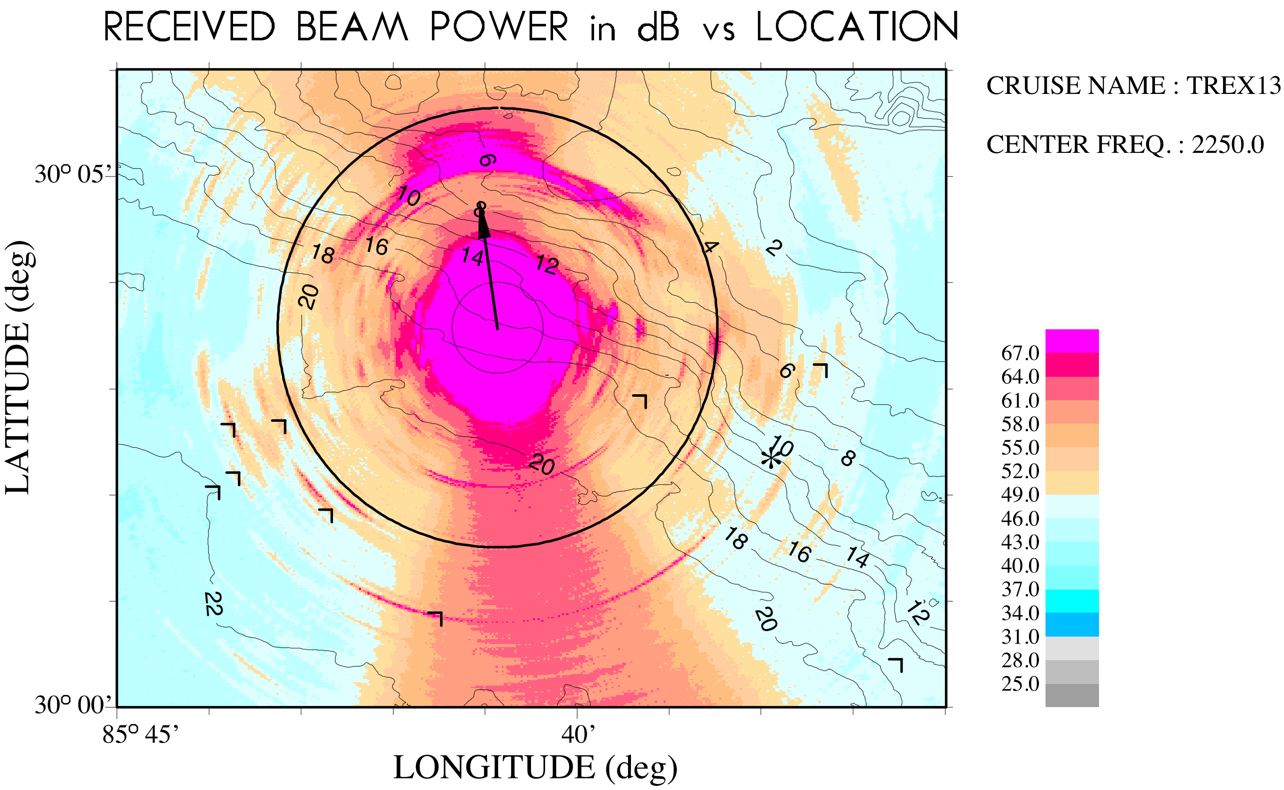

Fig. 4 Polar plot of reverberation vs. location from TREX13 using the FORA off Panama City, Fl from a 1 s LFM; 1800–2700 Hz (triplet beamforming). Water depth 18 m; source depth 17 m; receiver depth 16 m. Black angle bracket symbols show the locations of shipwrecks and other man-made sources of clutter.

REFERENCES

[1] C. W. Holland, J. R. Preston, D. A. Abraham, "Long-range acoustic scattering from a shallow-water mud-volcano cluster," *J. Acoust. Soc. Am.* **122**, 1946-1958 (2007).

[2] D. T. Hughes, "Aspects of cardioid processing," SACLANT Undersea Research Centre, La Spezia, Italy, SACLANTCEN Rpt SR329A, 2000.

[3] J. R. Preston, D. D. Ellis and R. C. Gauss, "Geoacoustic parameter extraction using reverberation data from the 2000 Boundary Characterization Experiment on the Malta Plateau," IEEE *J. Oceanic Engineering*, 30(4):709–732, 2005.

[4] J. R. Preston, "Using triplet arrays for reverberation analysis and inversions," IEEE *J. Oceanic Engineering*, 32(4):879–896, 2007.

[5] J. R. Preston and D. D. Ellis, "Extracting Bottom Information from Towed-Array Reverberation Data. Part I: Measurement Methodology," *J. of Marine Systems*, **78**, S359–S371, 2009.

[6] D. D. Ellis and J. R. Preston, "Extracting Bottom Information from Towed-Array Reverberation Data. Part II: Modelling Methodology," *J. of Marine Systems*, **78**, S372–S381, 2009.

[7] E. K. Westwood and C. T. Tindle and N. R. Chapman, “A normal mode model for acousto-elastic ocean environments,” *J. Acoust. Soc. Am.*. **100**, 3631-3645 (1996)

[8] D. D. Ellis, “A shallow-water normal-mode reverberation model,” *J. Acoust. Soc. Am.,* **97**, 2804-2814 (1995).

[9] J. R. Preston and D. D. Ellis, “A Matlab and normal mode based reverberation model,” 2nd International Conference on Underwater Acoustic Measurements: Technologies and Results, Heraklion, Greece, June 2007.

[10] J. R. Preston and D. D. Ellis, “A normal mode and Matlab based reverberation model,” Paper for the ONR Reverberation Modeling Workshop proceedings, Apr. 2007.

[11] J. R. Preston and D. D. Ellis, “Model Summary of NONAME,” Presentation for the ONR Reverberation Modeling Workshop in Austin, Nov. 2006.

[12] E. I. Thorsos and J. S. Perkins, Overview of the reverberation modeling workshops, In Nielsen et al. [13], pages 3–14.

[13] P. L. Nielsen, C. H. Harrison, and J. Le Gac, editors, International Symposium on Underwater Reverberation and Clutter, NATO Undersea Research Centre, La Spezia, Italy, 2008, Conference held at Villa Marigola, Lerici, Italy, 9–12 September 2008.

[14] Dale D. Ellis, John R. Preston, Paul C. Hines, and Victor W. Young, Bistatic signal excess calculations over variable bottom topography using adiabatic normal modes, In Nielsen et al. [13], pages 97–104.

[15] M. Zampolli, M. A. Ainslie, and P. Schippers, Scenarios for benchmarking range- dependent active sonar performance models, In Proceedings of the Institute of Acoustics 32, Part 2 – Research Symposium, 2010.

[16] D. D. Ellis and J. R. Preston, “A comparison of broadband reverberation and clutter data from two directional arrays on the Malta Plateau,” presented at 2nd International Conference on Underwater Acoustic Measurements: Technologies and Results, Heraklion, Greece, 25-29 June 2007.

[17] J. R. Preston and D. D. Ellis, “A Matlab and normal mode based adiabatic range-dependent reverberation model,” 4th International Conference on Underwater Acoustic Measurements: Technologies and Results, Kos, Greece, June 2011, pages 667-674, (Invited).

[18] J. R. Preston, K. M. Becker, P. Shultz and J. McIlvain, “An overview and lessons learned from the five octave research array (FORA) and some perspectives for future towed arrays,” 4th International Conference on Underwater Acoustic Measurements: Technologies and Results, Kos, Greece, June 2011, pages 1241-1248, (Invited).

[19] D. D. Ellis and J. R. Preston, “DRDC Clutter Model: Range-dependent predictions compared with towed array reverberation and clutter data from the Malta Plateau,” 4th International Conference on Underwater Acoustic Measurements: Technologies and Results, Kos, Greece, June 2011, pages 657-664, (Invited).

[20] D. A. Abraham and J. R. Preston, “Statistical analysis of monostatic and bistatic echoes from shipwreck clutter,” 4th International Conference on Underwater Acoustic Measurements: Technologies and Results, Kos, Greece, June 2011, pages 629-636, (Invited).

[21] Hee-Chun Song, Steve Cho, Taehyuk Kang, William Hodgkiss, and John Preston, “Long-range acoustic communication in deep water using a towed array," *J. Acoust. Soc. Am. Express Letters* **129**, EL71-EL75 (2011).

[22] J. R. Preston and D. D. Ellis. Report on a normal mode and Matlab based reverberation model. Technical Memorandum TM 2006-290, DRDC Atlantic, Dartmouth, NS, Canada, June 2008.

[23] J. R. Preston, Some initial findings from the very shallow water GULFEX12 reverberation experiment using the FORA, Paper 1pUW4 for 164tst ASA meeting in Kansas City MO, Oct. 2012.

[24] D. A. Abraham and A. P. Lyons. Reverberation envelope statistics and their dependence on sonar bandwidth and scatterer size. IEEE Journal of Oceanic Engineering, 29(1):1–12, January 2004.

PUBLICATIONS

[A1] J. R. Preston, “Results from the very shallow water GULFEX12 reverberation experiment using the FORA triplet array”, The 1st Underwater Acoustic Conference in Corfu, Greece, June, 2013. (Invited) [PUBLISHED].

[A2] D. D. Ellis and J. R. Preston, “Comparison of model predictions with reverberation and clutter data in a range-dependent shallow water area”, The 1st Underwater Acoustic Conference in Corfu, Greece, June, 2013. (Invited) [PUBLISHED].

[A3] 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].