

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

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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**

- Help plan, participate in, and analyze data from the GULFEX12 pilot and TREX13 Reverberation experiments, the 2014 Nordic Seas experiment. The PI's technical objectives for the experiment 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, and the 2014 Nordic Seas 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 last year near Panama City. It was focused on the characterization of very shallow water reverberation. The PI will use his 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 first 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 2017 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. 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 (an article for J.O.E. was published this year). 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. 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**

Since the TREX13 Experiment 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, K-distribution fits to the matched filtered amplitude data and polar plots. This suite of tools can now be made available to any future users of FORA.

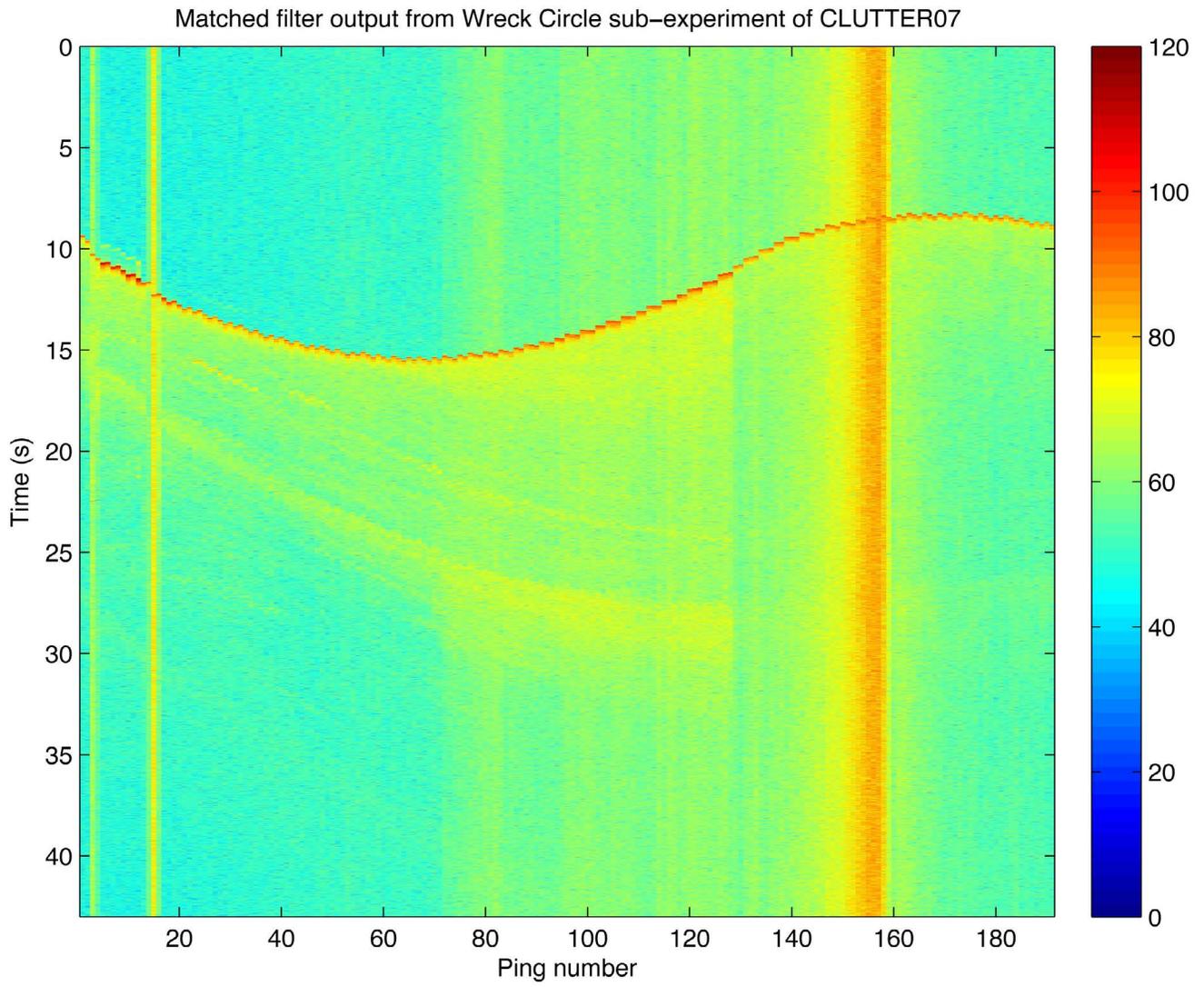
In 2015 the Automated Reverberation Processing System (ARPS) has been upgraded to work on towed FORA data rather just fixed-fixed data from the TREX13 Experiment and K-distribution fits to the data are now broken out by time increment and beam, rather than just by beam.

The PI has also spent some 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.

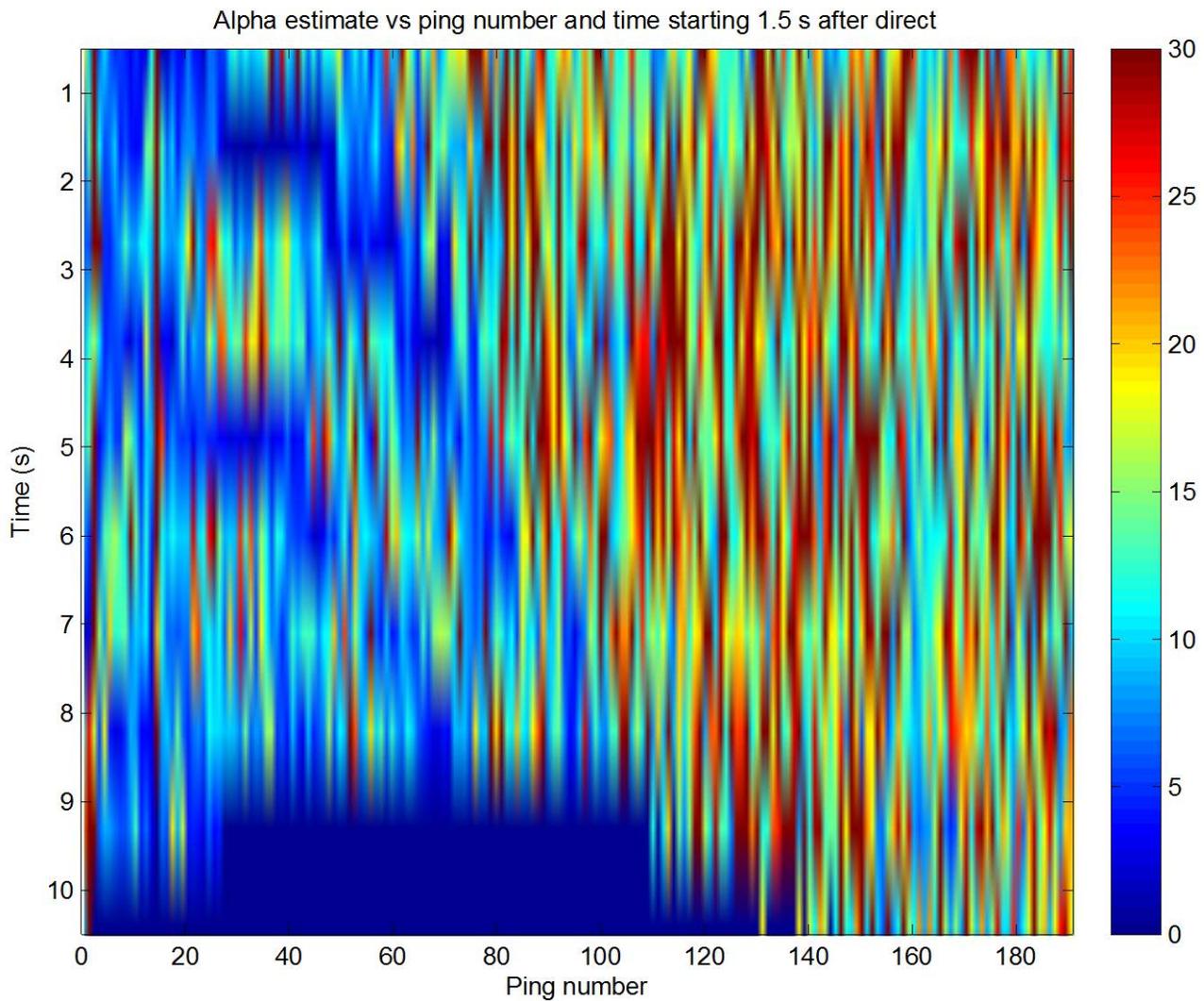
## **RESULTS**

### **Some Preliminary Data Processing Results**

Figures 1 and 2 are from towed FORA data taken in 2007 after using the new ARPS. The data are from the first shipwreck circle sub-experiment taken in the CLUTTER07 Experiment. Figure 1 shows 191 consecutive bistatic pings spaced 60 s apart using a 1 s LFM pulse from 800 – 1800 Hz. Results are after using a triplet beamformer and steering the output to 129 Deg. True. The direct arrival is the sinusoidal shaped return between 10 and 15 s after the start of recording. Also shown after the direct are 2 returns visible at increasing times after the direct. Near ping 1 they come in around 12 and 16 s after start of recording. By ping 70 they come in about 20 and 25 s after recording start. Figure 2 shows the K-distribution shape parameter, alpha, which is a measure of how non-Rayleigh the data are vs. ping number and time. Values of alpha less than 10 are usually strongly non-Rayleigh while values greater than 20 are usually very Rayleigh-like. Time in this plot starts 1.5 s after the direct arrival. The two deep blue valleys on the right roughly correspond to the two other arrivals in figure 1 suggesting they are strongly non-Rayleigh..



*Figure 1 Matched filter output in fixed look direction over 191 bistatic pings of Wreck Circle Experiment from Clutter 07*



*Figure 2 Shapr parameter Alpha vs ping number and time from Clutter07 sea trial (see text).*

Regarding the FORA maintenance, this year's work has centered around assessing repairs to FORA at Teledyne Instruments in Houston TX (actual repairs are being done under a different ONR program).

## **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.

## REFERENCES

- [1] 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.
- [2] 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.
- [3] 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.
- [4] J. R. Preston, “Using triplet arrays for reverberation analysis and inversions,” *IEEE J. Oceanic Engineering*, 32(4):879–896, 2007.
- [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.
- [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 164<sup>th</sup> 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 and D. A. Abraham, "Statistical analysis of multi-static echoes from a shipwreck in the Malta Plateau," *IEEE J. Oceanic Engineering* July 2015. {PUBLISHED}.