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 and the 2015/2016 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 Nordic Seas experiment, the 2015 Bottom Characterization Pilot experiment and the main 2016 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 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 2015/2016 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 accepted 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 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 TREX13 experiment results; preparation and participation in the Nordic Seas experiment; and FORA processing software improvements. An initial TREX13 paper was presented at the 2013 ASA San Francisco meeting and a modeling paper with Ellis as first author was presented at the 2014 UAC conference in Rhodes , 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, 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.

The PI has also spent some effort this year in asasesing 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

Figure 1 shows a sequence of matched filtered time series along the designated clutter track of TREX13 for run 17. This was an overnight run so the first 120 pings span about 9 hours. Fixed targets show up as horizontal lines and moving targets show up as lines with a tilt from horizontal. But the interesting non-stationary and diffuse returns between 3.5-5.5 s and in the first 40 pings appear to be biologic scatterers, most likely a fish school. The signal used was a 1 .0 s long, 100 Hz wide LFM from 3400–3500 Hz.

Figure 2 shows a similar result for another overnight run number 69 using the same signal. Again biologic like returns can be seen between pings 10 and 80 in the 7 to 9 s region.

Figure 3 shows the same run but with the wide band LFM 1.0 s long from 27003600 Hz. Some of the same biologic scattering present in the previous plot is visible here also.

Finally, from collaboration with Doug Abraham the reverberation portion of the matched filtered and normalized time series (not shown) is used to estimate the K distribution fit to reverberation. Since this fit involves 2 parameters, a shape and scale parameter one can use the shape parameter as way to say how much the reverberation time series deviates from Gaussian behavior. Namely, when the shape parameter is around 10 or below the amplitude statistics will be heavy tailed or noon-Gaussian and if it is greater than about 20 the statistics will be close to Gaussian. Fig. 4 is a sample plot of the estimated shape parameter for each ping of run 17, using the same narrowband LFM, along both the nominal clutter track (240°T) and the nominal reverberation track (129°T). In this example the data are mostly heavy tailed or non-Gaussian for this relatively narrowband LFM.

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.

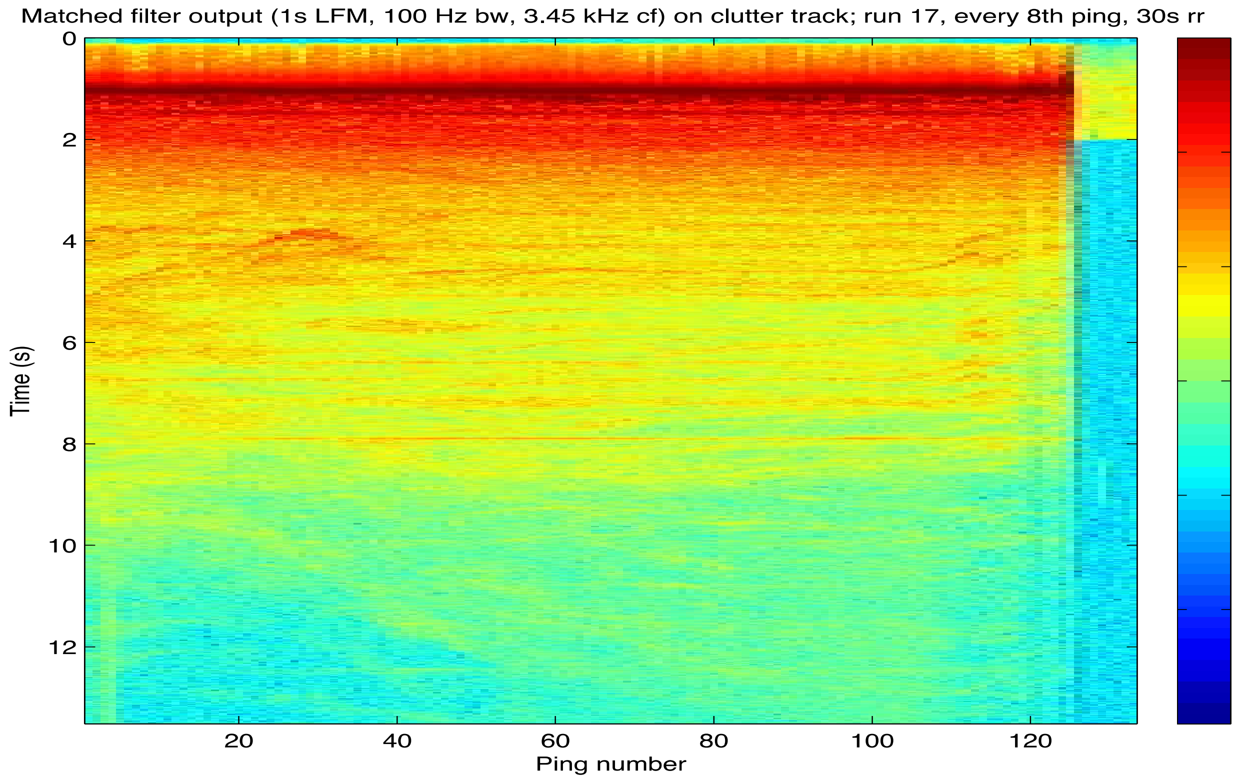

Fig. 1 Plot of beam time series from overnight run 17, by ping number from TREX13 for a triplet beam along the 240° T bearing (clutter track), using a 1.0 s LFM from 3400–3500 Hz.

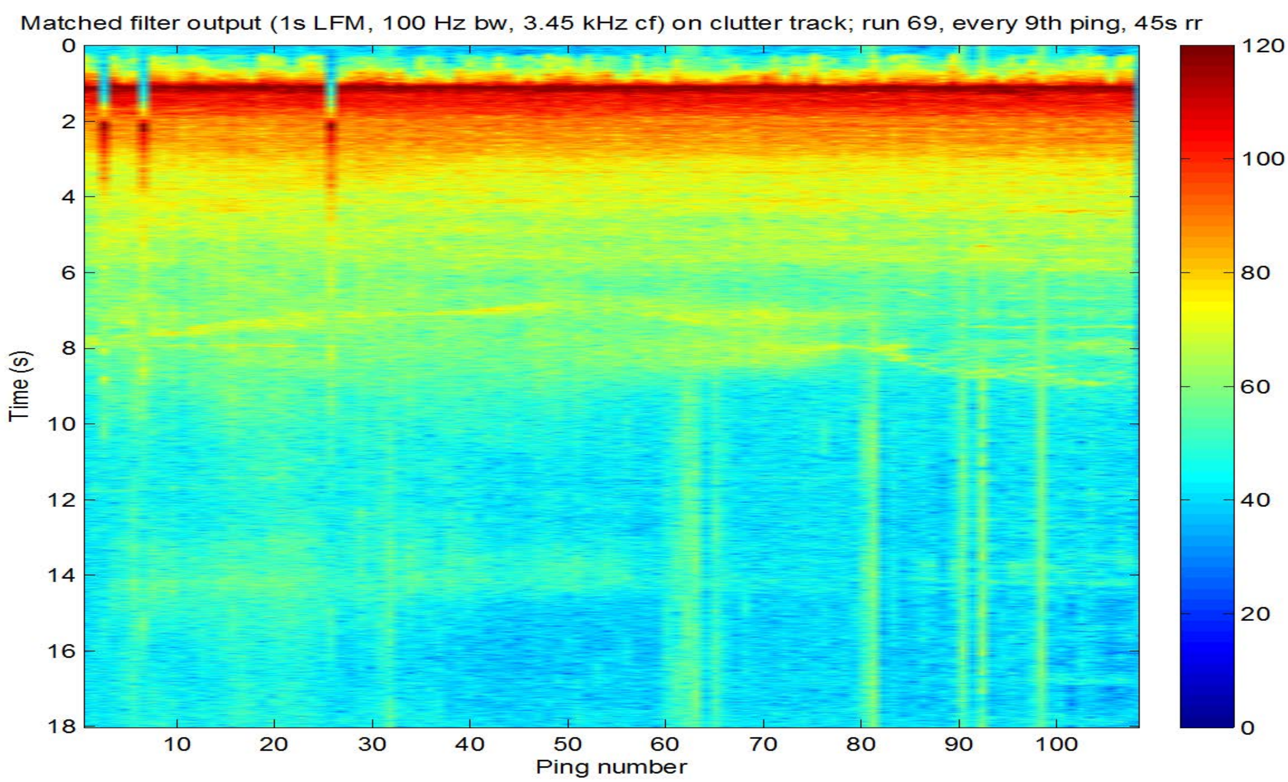

Fig. 2 Plot of beam time series from overnight run 69, by ping number from TREX13 for a triplet beam along the 240° T bearing (clutter track), using a 1.0 s LFM from 3400–3500 Hz.

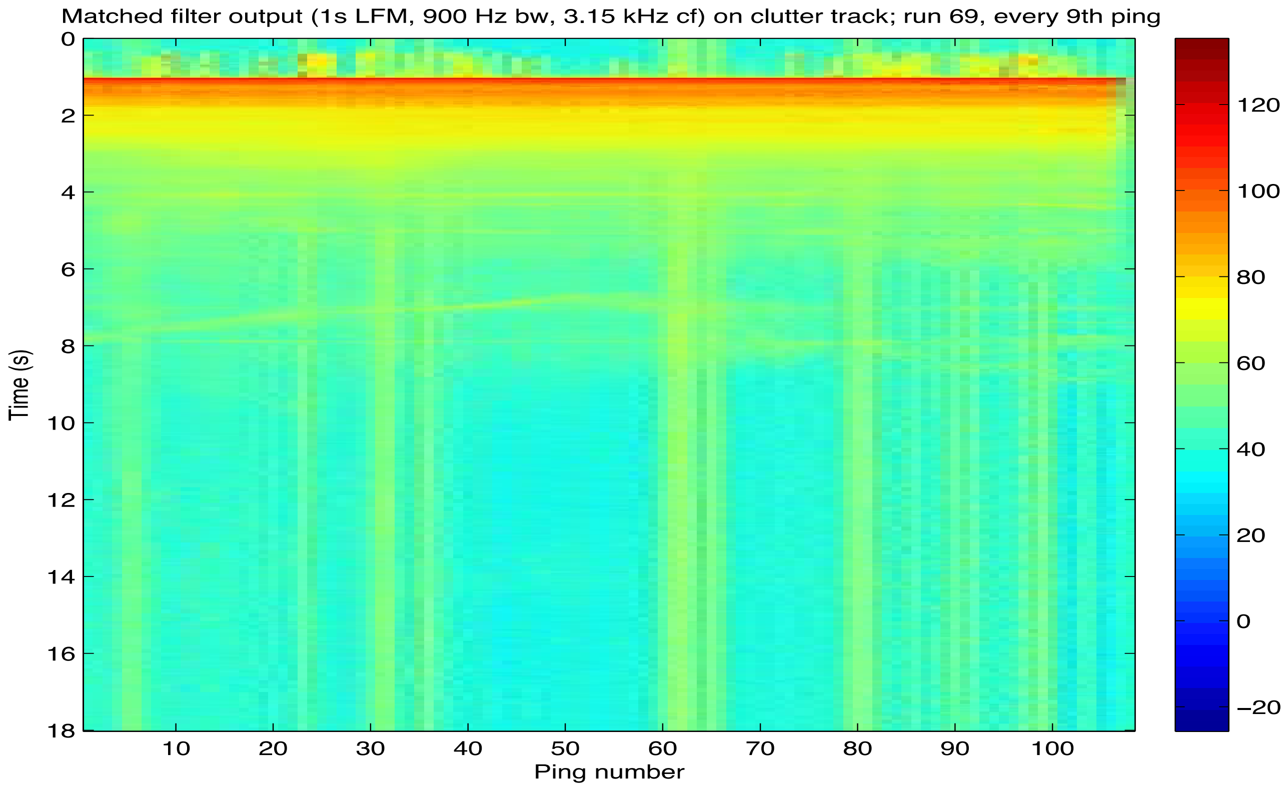

Fig. 3 Plot of beam time series from overnight run 69, by ping number from TREX13 for a triplet beam along the 240° T bearing (clutter track), using a 1.0 s LFM from 2700–3600 Hz.

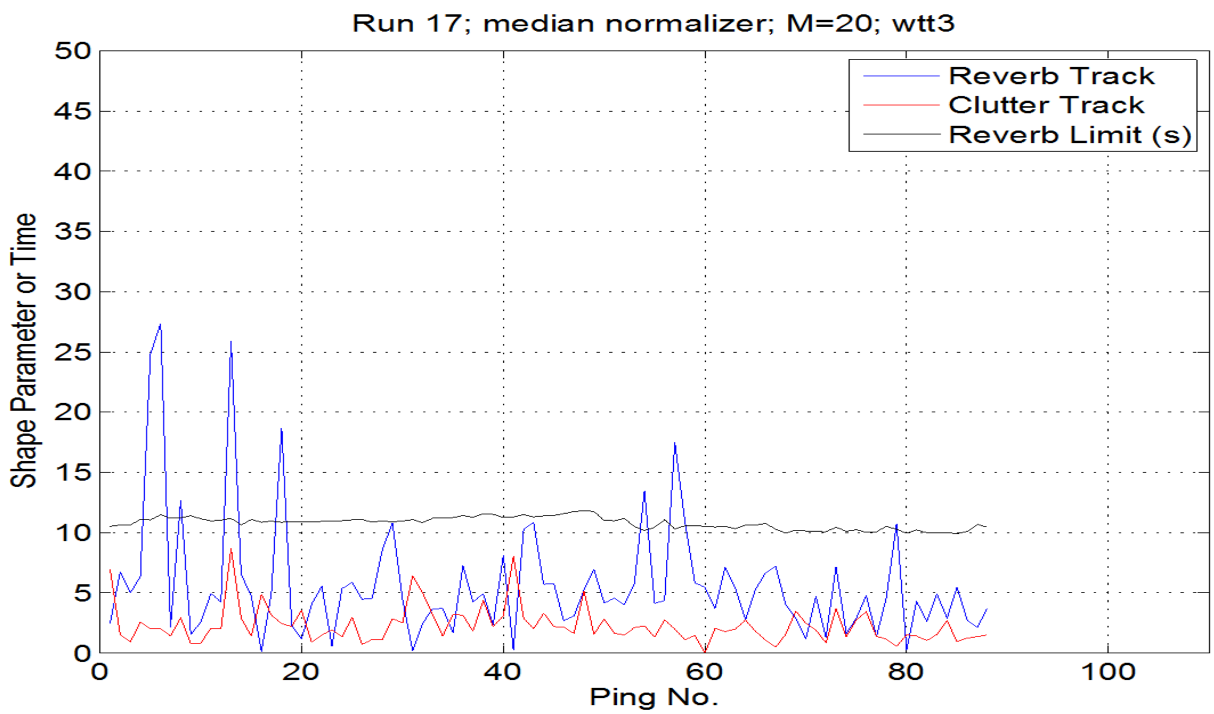

Fig. 4 The K-distribution shape parameter estimate by ping number is shown for Run 17 for both the reverb track bearing (129°T) and the clutter track bearing, suggesting a mostly non-Rayleigh character to the reverberation for this signal (a 1.0 s LFM from 3400–3500 Hz).

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