MEASUREMENT ISSUES IN MID-FREQUENCY REVERBERATION EXPERIMENTS

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1 INTRODUCTION

A basic research reverberation experiment, supported by the US Office of Naval Research, is planned for 2013. Measurement issues that arise when planning such an experiment are discussed. The fundamental requirement for this basic research experiment is that the environment is characterized in sufficient detail to allow accurate numerical modeling of the acoustical results based on the environmental description.

Modeling shallow water reverberation is a problem that consists of two-way propagation (including multiple forward scatter) and a single backward scatter. In order to understand the reverberation problem at the basic research level, both propagation and scattering physics need to be properly addressed concurrently. Some aspects of reverberation are best treated stochastically – roughness scattering from the bottom and surface, for example. Other aspects can be more successfully treated deterministically, such as waveguide propagation and target scattering. Yet there are aspects where experience is limited, and the approach used to model them will likely be determined based on further empirical investigations. To further basic reverberation study, we strive to have the environment sufficiently measured to support full modeling of the data. It is only after all components that affect the reverberation are well measured and modeled that a true understanding of the reverberation problem can be achieved.

The main goal is to measure mid-frequency shallow water reverberation with full companion environmental measurements so that model/data can be compared without ambiguity. Included in the goal is to make statistical estimates of the uncertainties associated with all the environmental conditions. The frequency range of interest is 1-10 kHz with emphasis at 3 kHz.

While the relevant water depth covers the entire continental shelf, the key issue for reverberation is small grazing angle propagation and scattering in a waveguide. A major burden of this experiment program is measuring the environment that influences reverberation. Reducing the region over which the environment needs to be characterized becomes a primary consideration. By reducing the water depth to about 20 m, the range at which the sound field is dominated by small grazing angle propagation and scattering is shorter than at deeper depths. Therefore, environmental measurements can be limited to a smaller area. Another advantage of working in such a water depth is that diver support at the bottom is available, which provides added control of the various measurements. Finally, from an environmental standpoint, the shorter ranges allow lower source levels to be used, and therefore the measurement program can be more easily made compatible with environmental regulations. By choosing this water depth, we are also mindful that some oceanographic processes, such as ripple field and sediment heterogeneity, are different from those in deeper water. We emphasize, however, that this shallow depth offers the best chance to study basic science issues, the understanding of which can be applied to more general environments.

Directional sources and horizontal receive arrays will be used such that only a 2-5 degree wedge-shaped ocean needs to be measured for environmental support. The horizontal arrays will not be towed, but rather be mounted by clipping to a taut line supported by two poles. This stationary arrangement ensures any variation of reverberation level over time is due solely to environmental changes, rather than instrument motion. Propagation and forward scatter will be measured, concurrent with reverberation measurement, on vertical arrays at several ranges along the wedge-shaped track to understand their temporal and spatial impact on reverberation. One key issue for the reverberation experiment is to ascertain the dominant bottom backscatter mechanism: rough water/bottom interface, subbottom heterogeneity, or an as yet un-anticipated source. To this end, bottom reflection and backscatter as a function of angle will also be measured along the track to understand local backscatter variability.

An anticipated outcome of this experiment is to determine which aspects of the complex environment can, for certain applications, be safely ignored when considering modeling where some fidelity can be sacrificed in the interests of speed.

2 EXPERIMENT SITE AND MEASUREMENT LAYOUT

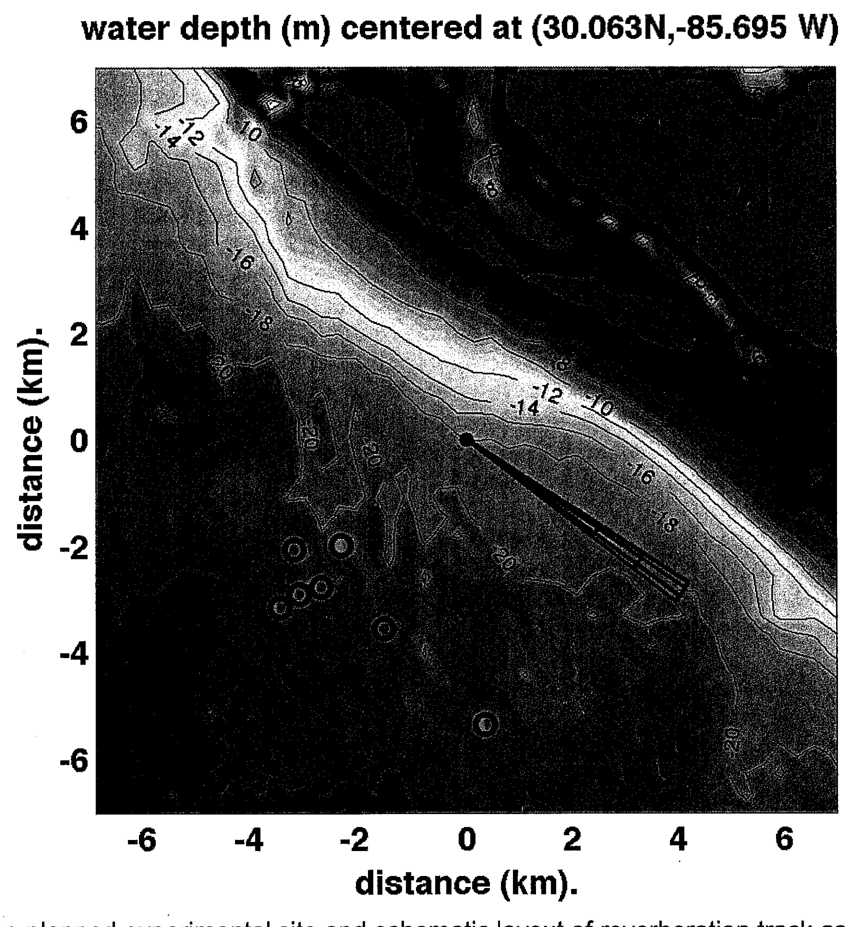

Figure 1. The planned experimental site and schematic layout of reverberation track as given by the red wedge. The thick black circles are known ship wrecks or other clutter.

Figure 1 shows the location of the experiment site off Panama City, Florida. The center solid dot in the figure indicates the spot where a research vessel will be 4-point moored. This moored ship provides a platform to support reverberation measurements. The red wedge in the figure symbolizes the "reverberation track" where the reverberation data will be taken, and where measurement of environmental parameters will be concentrated.

Two horizontal line arrays will be employed for redundancy. They would be deployed about 2m above the seafloor, side by side separated by ~20m. One of the arrays is the "triplet" section of FORA array (Five-Octave Research Array), which has a beam width of 2 degrees at 3-4 kHz and has the ability to discriminate left/right ambiguity. A horizontally omni-directional source, an ITC-2015, will work in tandem with the FORA. The second array is a 32-element linear (HAARI) array, which will work with two directional sources; an ITC-5485 for 2-5 kHz, and an ITC-5490 for 9 kHz. Fig. 2 shows an underwater picture of the HAARI array and the companion source in a deployment in 2011. In order to make simultaneous measurements of reverberation and propagation/forward scatter, several vertical line arrays will be deployed long the reverberation track, separated nominally by a kilometer from one another. These vertical arrays will record the same transmissions that the horizontal arrays will record. This arrangement enables the examination of impact on reverberation by propagation under different weather conditions. Bottom reflection and backscatter will be measured as a function of grazing angle along the reverberation track to quantify their spatial variability.

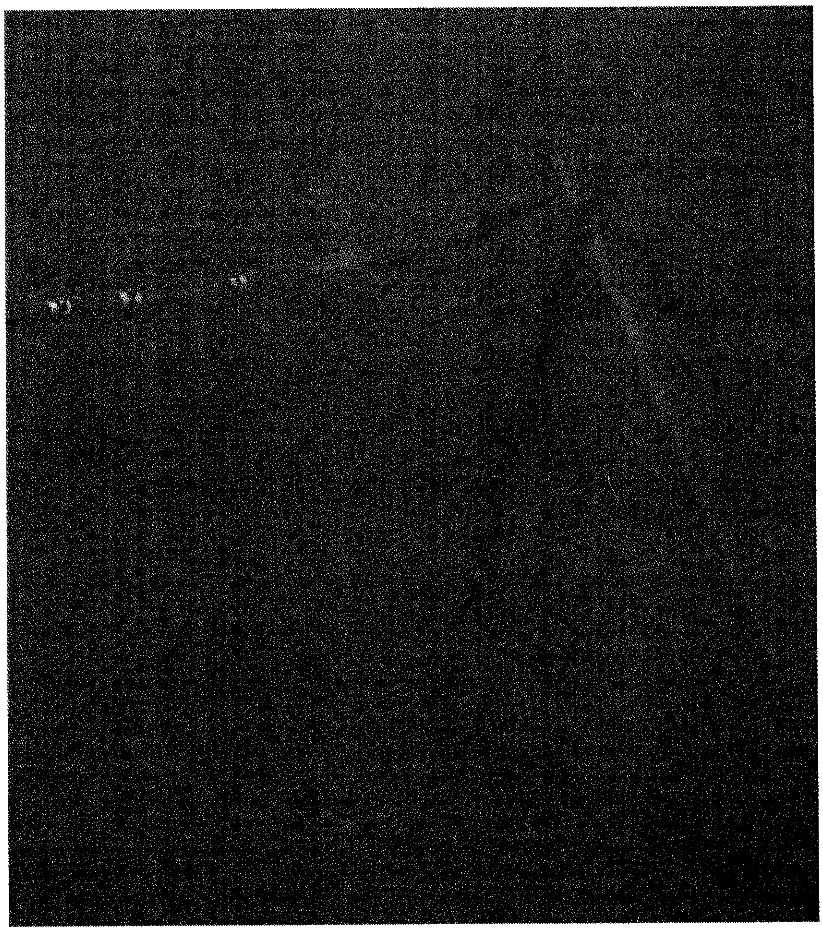

Figure 2. Underwater picture of the 32-element HAARI array in a 2011 deployment.

At this site, a geo-acoustic survey was conducted in April, 2011, and a pilot acoustic experiment in April, 2012. The geo-acoustic survey consisted of detailed chirp sonar survey for sub-bottom structure, high-frequency multi-beam scan for surficial topography, and several vibrocores. The sediment at this site is found to be composed of 1–3 m of sand over a layer of shell hash that in turn overlies mud. The multi-beam scan resulted in high-resolution bottom topography, which provides the opportunity to model bottom forward scatter under the influence of small topography variation.

The sound speed profiles in the month of April obtained from the 2011 and 2012 experiments at the site show a nearly constant sound speed around 1530 m/s, with variation from the surface to bottom of less than 2 m/s. It is expected that a thermocline will gradually develop starting in May. The wind conditions and surface waves change daily, offering opportunity to study their impact on propagation and reverberation.

Environmental measurements in the 2013 main experiment will be extensive, including sea surface directional wave spectrum, bottom roughness and in situ sediment sound speed along the reverberation track, as well as subbottom profiles and images. A multibeam survey will again be made to cover the entire reverberation track to give detailed seafloor topography along the reverberation track. In addition, the multibeam data will also be able to help identify bottom ripple fields and changes of surfacial material properties of the seafloor. Sediment sound speed will be measured by the in-situ acoustic probe called the Sediment Acoustic Measurement System (SAMS) to a depth of 1-2 m in the frequency band of 2-12 kHz. An attenuation array will measure surficial sediment sound speed and attenuation in the band of 50-200 kHz. Diver cores will be collected to estimate sediment grain composition and bulk density. Micro-scale bottom roughness on the order of the acoustic wavelength will be measured along the reverberation track using laser line scanners and conductivity probes. Such micro-scale roughness could be a substantial contributor to bottom backscatter. Sub-bottom volume heterogeneity could be another mechanism for bottom backscatter. A sub-bottom acoustic imaging system will be used to identify the presence of volume heterogeneity such as mud lenses suspended in sands. In addition, a sediment conductivity system will provide a measure of sediment porosity variation.

3 PRELIMINARY RESULTS

Results from the 2011 and 2012 field work are summarized, which help to narrow down the range of parameter space for modeling purposes. The surficial sand to a depth 1 m is found by the SAMS to have a mean sound speed of 1670 m/s ± 10 m/s. Because the horizontal receiving arrays are close to the moored ship, combined ambient and ship noise is a factor that limits the reverberation range. A sample noise spectrum is given in Fig. 3. The variations of the noise level can fluctuate 5 dB around the values in the figure.

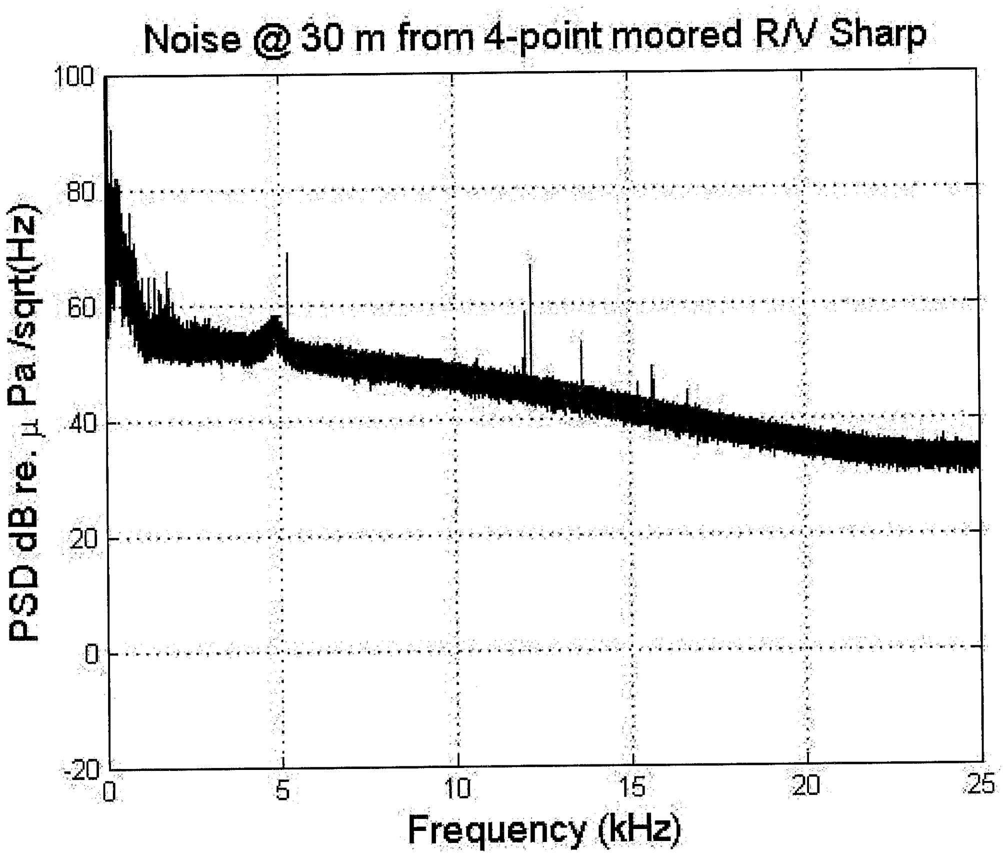

Figure 3. Ambient noise spectrum measured 30 m away from the 4-ping moored research vessel, the R/V Sharp. The line spectra and the small peak near 5 kHz are from the Sharp's self noise.

One primary goal for the 2012 pilot experiment is to determine the range of measurable reverberation over the noise background. Fig. 4 is a 10-ping average of reverberation level from a 100-ms long, 3.5 kHz tone vs. ambient noise on a single element of the HAARI array from the ITC-5484 source at 203 dB re 1 μPa. This result demonstrates that reverberation at this source level can be measured to at least 6 km. With beamforming gain, the range can be extended to 8-10 km, sufficient for the intended scope of the planned experiment.

The IMP2, a laser line scanner, was deployed several times and a preliminary 2-D bottom roughness spectrum is obtained as power law with exponent γ_2 =3.234, and strength w_2 = 4.1656 x 10^{-5} $m^{4-\gamma 2}$.

Finally, several long time series of reverberation, over 10 hours in duration each, were recorded. During those time period significant changes of surface waves were observed. These time series will provide the opportunity to start examining the relationship between surface conditions and reverberation level variability, a necessary preparation for the main experiment in 2013 when surface wave conditions will be quantitatively recorded along with the acoustics.

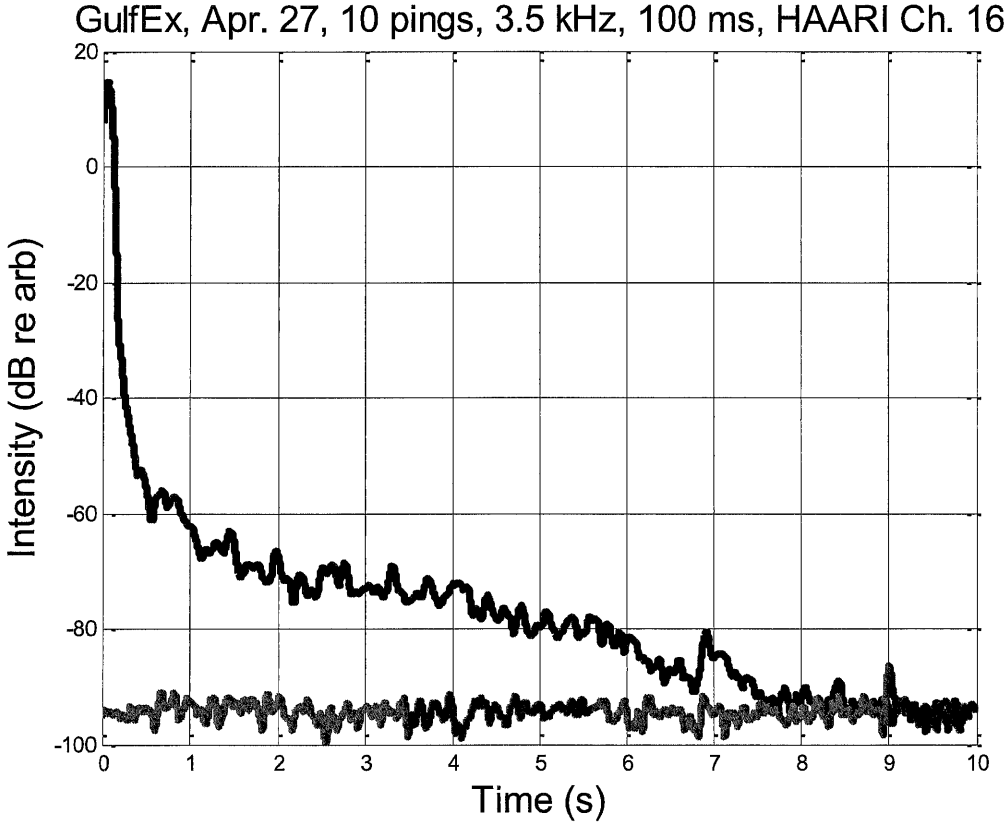

Figure 4. Reverberation intensity (blue) and ambient noise level vs. time at 3.5 kHz.

SUMMARY

While the results of the preliminary tests in 2011 and 2012 show that reverberation can be measured to sufficient distances, complete modeling of the problem relies on extensive environmental characterization and measurement of forward scattering. The 2013 experiment will bring a number of resources and systems to bear on this problem making it possible to create a comprehensive reverberation dataset that can complement previous and ongoing reverberation workshops and modeling efforts. It will also provide an opportunity to determine which scattering mechanisms most influence the reverberation and to understand factors such as the evolving sea state and sound speed profile over time.

ACKNOWLEDGEMENTS

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