Summary
ONR Workshop on Reverberation Field Experiment
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Mid-frequency reverberation measurements with full companion environmental support
White Paper

Long-term Goals: Understand and accurately model 1-10 kHz reverberation and its uncertainty in shallow water environments, including clutter mechanisms.

Background: 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. 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 by further empirical investigations. Scattering from fish schools and shipwrecks along with biological aggregates around them falls into this category. To further 6.1 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.

Main goal: 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. A key element is to understand the mechanisms that cause clutter.

Frequency range: 0.5-10 kHz, but environmental information prioritizes 3 kHz and higher.

Navy relevance: Submarine detection using active surface ship sonar is in most cases based on monostatic scatter and is reverberation limited. Many new MCM systems also include mid-frequency components and are likewise reverberation limited.

Water depth and argument for its choice: 20-30 m.

Argument: The relevant water depth for naval applications 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 measured becomes a primary consideration. By reducing the water depth to between 20 and 30 m, the range at which the sound field is dominated by small grazing angle propagation and scattering is proportionally shortened. 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.

Propagation and Scattering mechanisms to be addressed: Bottom roughness (including ripples); water column variability; surface roughness as a function of wind speed and direction; fish school properties; sediment heterogeneity (e.g., mud inclusions); near surface bubbles; and known clutter such as ship wreckage.

Supporting Measurements: Along the propagation path, sediment geo-acoustic parameters to a depth of 2-3 m; water column sound speed field over time; sea surface roughness, mean-square long-wave slope, and directional properties as a function of time; shipwrecks; and presence of fish schools and their characteristics over time. Surface backscatter measurements can also be used to infer the presence of bubbles as indicated by elevated scattering over that expected from surface roughness alone.

Approach: Instead of omni-directional transmit and receive transducers, horizontal receive arrays will be used such that only a 2 degree wedge-shaped ocean needs to be measured for environmental support. A possible candidate array is the triplet section of the ONR FORA (Five Octave Research Array). It has a high-frequency triplet horizontal aperture of 15.6 m, and is cut for a center frequency of 3750 Hz. Its beam width is less than 2 degrees. The horizontal array will not be towed, but rather be mounted to a horizontal line supported by two towers 2-5 m above the bottom. The bottom-mounted array will attract fish. This problem will be addressed by using a simple tower/array setup that allows the array to be moved periodically by divers. This arrangement also allows orientation to include or exclude known bottom debris fields and alter orientation relative to ripple fields, if present. At each location of the array, the time evolution of the reverberation will be measured.

Other basic science issues to be addressed in this project: Reverberation measurements necessarily include propagation (two-way) and scattering. Therefore, in order to properly model reverberation, both propagation (including forward scatter) and backscatter have to be measured and understood. As such, the reverberation organically integrates many shallow water acoustics issues under one theme, providing a scenario where the various shallow water problems can be evaluated comprehensively. Specific basic science issues to be addressed in addition to the reverberation are as follows:

1. Mid-frequency sound intensity scintillation index and coherent field. During the SW06 experiment, the scintillation index as a function of frequency was obtained, and was found to be consistent with a focusing effect due to ambient internal waves. However, no existing theories explain the measurements. This recent result strongly suggests a new area of investigation for WPRM (Wave Propagation in Random Media) in shallow water. Further measurements of scintillation, complemented by measurement of the coherent field where both source and receiver positions are known to within a fraction of a wavelength, will further our understanding of uncertainty in shallow water acoustics in general, and provide a basis for estimating uncertainties of geo-acoustic inversion in particular.
2. The evolution of mid-frequency spatial coherence as a function of range from source. Vertical coherence incorporates propagation physics and relates to reverberation versus time.
3. Sediment sound speed and attenuation as a function of frequency (800 – 10,000 Hz). Existing instruments such as SAMS and new instruments under development will make it possible to help clarify the issue of sediment sound speed dispersion.
4. It has been observed that bottom scattering strength is a spatially varying quantity; however, the spatial variability of backscatter as a function of frequency and grazing angle should be measured with adequate environmental support. Bottom scattering strength is a key ingredient for reverberation. We propose to separately make bottom backscatter measurements over the entire area that contributes to reverberation.
5. Sediment ripple fields in shallow water have been demonstrated (SAX99, SAX04) to strongly influence penetration into the sediment and target scattering. The ripple effects on waveguide propagation and sediment volume scattering have not been experimentally investigated. The proposed reverberation experiment requires detailed measurement of bottom topography, including ripple fields, hence offering an opportunity to investigate the ripple field impact on mid-frequency acoustics.

Location: Gulf of Mexico (Panama City Beach, FL).

There has been extensive acoustics related work conducted in this area, primarily because of the presence of the Naval Surface Warfare Center, Panama City Division (NSWC PCD). NSWC-PCD could also provide excellent logistical support for the proposed work if done in that area. The bottom topography in the entire area is relatively flat with a gentle slope, providing range-independent (parallel to shore) and range-dependent (perpendicular to shore) environments.

Ripple fields are often present in the region, providing an opportunity to investigate their impact on mid-frequency acoustics. Fish have been consistently found in this area, which will be important in investigating effects of fish on reverberation. In addition, there exist maps which detail the type and location of shipwrecks, which could be used as natural clutter. Recently, a reconnaissance experiment was conducted in that area, including a chirp sonar survey, a multibeam survey, vibra-coring, and in situ measurement of sediment sound speed and roughness.

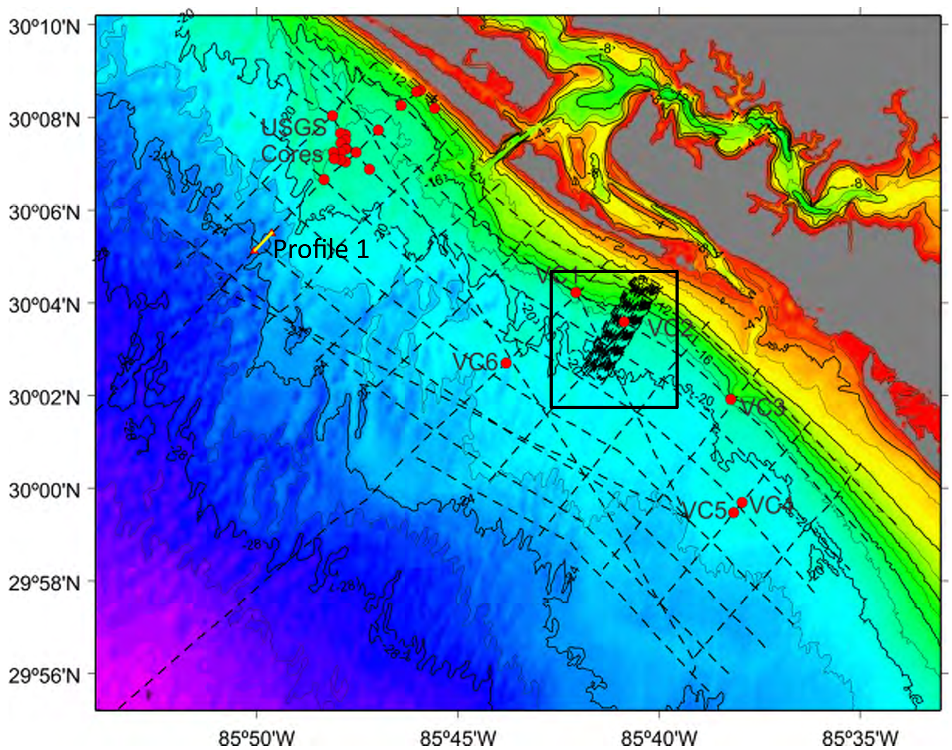

Figure 1: Chirp sonar survey of the experimental site off of Panama City Beach, FL conducted in the Spring of 2011 by John Goff. Chirp sonar tracks are shown as dashed lines. Vibracore locations are shown as red dots and those labeled with VC were collected during the chirp survey.

Time of field work: FY 2013

Topics Discussed

<u>Acoustics goals</u>:

- Reverberation
  - Mid-Frequency (0.5-10 kHz). Environmental information prioritizes 3 kHz and above and monostatic reverberation
  - Fixed HLA (2-5 degrees) and directional source (or triplet array) Best for 3-4 kHz, but will also be used in other frequencies.
  - Towed source and HLA.
  - ~20 m depth, 5 km range
  - Consider also bistatic geometry with separate source

- Waveguide propagation, forward scatter, and vertical coherence
  - Along fixed HLA track
  - 2 or more VLAs placed at ranges of 10 water depths and 100 water depths
  - Complemented by local, single path reflection measurements
- Backscatter
  - Along fixed HLA track, if possible, including vertically bistatic scatter.

<u>Environmental characterization to complement acoustic measurements:</u>

- Bottom properties along 5 km track within HLA beam
  - Bottom Roughness
  - Sediment density
  - Subsurface layers
  - Subsurface heterogeneities (mud flasers, etc.)
  - Sound speed and attenuation
  - Shear waves?
- Surface properties
  - Wave spectra
  - Surface bubbles
- Water column properties
  - Internal waves
  - Sound speed profiles
  - Winter
  - Summer
  - Fish: naturally occurring schools/shoals and those that are attracted to bottom-mounted instruments
  - Currents, temperature, etc.
- Ambient noise

Assets for environmental characterization

- Bottom Roughness
  - IMP2/LLS (Hefner)
  - ROV-LPS (Chotiros/Isakson)
  - Multibeam sonar (de Moustier/Reson)
  - Potential Flash Lidar (Lyons)
  - Side scan sonar (Gawarkiewicz)
- Subsurface layers and heterogeneity
  - Chirp sonar (Goff, Stanton, Turgut)
  - BOSS (NSWC PCD)
  - Vibracores (Goff, USGS)
  - SAMS (APL-UW)
  - Wide-angle reflection (Holland)
- Surface Wave Spectra
  - Directional wave buoys (Dahl) – 2
  - NURC marine radar analysis (radar actually ship asset)
- Surface Bubbles
  - Upward looking multibeam (Tom Weber)
  - Quadpods (NRL-Stennis)
  - Resonator or Optical systems for size distribution (Grant Dean, David Farmer)
  - Surface backscattering inversion – Dahl MK46
  - Video – geo-referenced and GPS
- Water Column
  - CTDs
  - ADCP (Gawarkiewicz)
  - Remus CTD (Gawarkiewicz)
  - Thermister chains (Gawarkiewicz, MPL)
  - CTD chain (APL-UW/ARL-Penn St, NURC)
  - Autonomous CTD units – APL-UW
- Fish
  - Chirp sonar (Stanton)
  - Side scan sonar (Gawarkiewicz)
  - HF backscatter (Stanton)
  - Sampling (Fisheries, Fishermen?)
  - Multibeam – Penn St/ UNH
  - Video monitoring at stationary platforms
  - Species identification
- Ambient noise
  - Ship traffic monitoring and radar log.

Assets: Acoustic sources:

- Hodgkiss
  - ITC-2040X and ITC-1001in a tow body (3-30 kHz)
  - ITC-2015 (1.5-4 kHz)
  - Chelsea SonoFlex-850 (800-900 Hz)
  - J-15-1 / J-15-3 (rental)
- Edgetech sources – 210 dB (directional), 100 ms limit pw, fully programmable.
- DRDC - LFA source towed 900-1800 Hz - VP2 – 220 dB

- Gauss
  - MF Source Array (2-9 kHz) 215 dB
- Turgut
  - Autonomous 4 element array (1-4 kHz) 200-210 dB
- Holland
  - Boomer (0.1-10 kHz) – rental – peak on-axis 220 dB
- APL-UW
  - ITC 1007 (2-20 kHz) 180-200 dB
  - ITC 2010x (1-4 kHz) 180-200 dB
  - ITC-2015
  - ITC-1007s
  - LF Projector (2-10 kHz)
- NURC – 215 dB autonomous, 2-3.5 kHz DEMUS, wireless comms, 3 day continuous operation
- CSS - ARL-UT
- Stanton
  - Beefed-up Edgetech Chirp Sonar

Assets: Acoustic arrays

- Hodgkiss
  - Autonomous receive array (128 channels)
- Preston
  - Fora triplet array (78x3 channels) stationary
  - Fora tow –adds 134 more channels/3 apertures
- Gauss
  - Line array receiver (32 element)
- Turgut
  - Reconfigurable 72 element array
- MPL
  - Fly by array (11 element)
- APL-UW
  - Moray (12 channels)
  - HAARI array (32 element)
- NURC – CPAM triple line
- ARL –UT SWAMI arrays 32 and 52 element

Assets: Acoustic targets

- Corner reflectors
- Echo repeaters - DRDC, NURC (1-4 kHz), NRL
- Artificial fish
- Real fish?
- Bubble cloud
- Target sphere (MPL)
- Minelike Targets
- Ship wrecks

Assets: Platform and others

- APL-UW rail system
- ARL-UT ROV
- MPL Deep sound (5 Hz to 40 kHz, vertical and horizontal 1 m Aperture)

Timeline

- Straddle winter and summer profiles
  - Possible April 20, 2013 – June 1, 2013

UNOLS Ships

- 1 moored (> 200 ft ?)
- 1 mobile (Oceanus?)

Canadian – Quest