Notes from Shallow Water Meeting – Seabed Acoustics Break-Out Group

Sept 30th, 2010

Facilitator: Ross Chapman

Slightly modified by David Knobles to only highlight those aspects associated with Seabed Characterization Experiment

Topic: Geoacoustic characterization experiment in environments that have strong ground truth at (ideally) range-independent bottom sites and benign water column conditions. The overall science objectives are:

- Characterize the geoacoustic environment using state of the art inversion methods over a broad frequency band: 25 Hz to 20000 Hz. A new issue here is the extension of the inversion techniques to higher frequencies (> 1 kHz).
- Investigate the dispersion of sound speed and attenuation in different sediment environments. The focus of this work is on sites that are not primarily sand bottom sites: stiff clay; mud; or silt/clay. This involves determining the frequency dependence of attenuation and sound speed in the frequency band from 100 to at least 5000 Hz.
- Investigate the effects of conversion of compressional waves to shear waves in the sediment. This involves measurement of elastic properties (shear speed) in the sediment.
- Determine the effect of an elastic solid bottom on propagation in shallow water. Ideally, an environment where the fast sound speed material is close to the sea bottom.
- Evaluate the performance of the geoacoustic inversion methods. The task is to design appropriate evaluation criteria for comparing the inversion results. Options are: transmission loss vs. range; Bartlett mismatch (vs. depth at fixed ranges; phase and amplitude matching); … There has to be agreement about the evaluation conditions.
- The process of geoacoustic characterization combines the objective of understanding the physical mechanisms of the interaction of sound with the ocean bottom, with the objective of estimating the statistical distributions of possible model parameter values. The reality is actually the statistical distribution, and this follows as a direct consequence of the inversion approach. The inverse problem does not have a unique solution, and so the solution is given in terms of the distributions of possible model parameter values. (David Knobles and Ross Chapman)
- Understand how the seabed characterization affects the 3-D nature of the ambient noise and reverberation. If we really "nail" the structure of the seabed that allows us to successfully predict transmission loss over large range scales and bandwidths, how well can we do in predicting the reverberation and ambient noise?
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- An unresolved issue from SW06 was the impact of uncertainty in the water column on performance of inversion methods in estimating geoacoustic profiles. Since there are very few sites where the impact of uncertain water column sound speed can be avoided, the effect of the water column will influence the experimental design.
- Although the focus of this group was on geoacoustic characterization and reverberation, there was extensive discussion about TL measurements over tracks to support both the reverberation and geoacoustic experiments.
- There was general agreement in using AUVs in design of experiments

I. New ideas about science objectives:

Comments on Scientific objectives from the group:

- Ross:
    - Dispersion of sound in different kinds of sediments.

- Orest Diachok:
    - Inversion methods should be tested at higher frequencies, 100Hz – 5 kHz. Select areas, which have fish populations to challenge inversion techniques. Bubble effects will begin to be important at higher frequencies.
    - Reverberation and TL: Not a lot of experiments consider both reverberation and TL. Most reverb models are untested in shallow water.
    - Expensive experiments should be conducted in areas that are close to operationally interesting areas, not just scientifically easy areas.
    - Consider merits of doing the experiment overseas where source level requirements may not be as stringent. (Ben Reeder – same requirements if funded by ONR)

- Peter Dahl
    - Concurrent coherence, TL, and reverb experiments.
    - Vector field properties (newly available to be measured) enable a new way to probe the physics of a shallow water environment.

- Mike Buckingham
    - Seabed other than sandy sediments have been neglected.
    - What effect does shear have on propagation?
    - Frequency ranges: 1-10 kHz range is difficult experimentally but essential. Consolidate bands (< 10 kHz, usually taken with reflection: > 10kHz usually taken with in situ) with similar measurements. (700Hz – 30 kHz SAMS)
    - Harbor defense, estuary experiments are more in line with current geo-political situations. . What is the ambient noise field in a harbor?

- Attenuation is highly variable, why?

- Jim Miller
  - Shear is interesting and elastic sediments would be an interesting topic.

- George Frisk
  - Hard bottom area vs. Soft sediment

- Anatoly Ivakin
  - Consider stratification
  - What minimum characterization needs to be conducted?

- JiXun
  - Navy is more interested in long range propagation so low grazing angle work is more important
  - Bottom acoustic and scattering model important.
  - What are we inverting for? When do we stop inversion? When is it applicable? Is the same forward model applicable over a large frequency range? How do we fill the gap between Navy application and research?
  - There is also a gap between reverberation modeling group and sea bottom scattering modeling. There is not a model describing the interaction between surface and bottom scattering.

- Marcia Isakson
  - Shear effects are important also in softer sediments.
  - Sediment has variability even for a single type over a range in impedance, roughness, and layer depth.

- Ben Reeder
  - The use of vector sensors may require 6.2 funding.

Afternoon Sessions:

II. A. Possible Sites (Rank in Parentheses)

- New Jersey Shelf (#1 for seabed characterization group)-
  - Thin layer of sand with an inhomogeneity in depth, Consistent layer of sand out 20 km. Also mud over sand area.
  - George Frisk – Likes site because it is very well characterized to compare experiments and models
  - Close to Southern New England Mud Patch (South of Martha's Vineyard)
    - soft sediment (recently deposited mud) over hard bottom (rough interface sand)
    - Location of proposed ocean observatory is near this site. (There will be high resolution models taken independently for this site 2014-2019. Measurements with AUVs, etc.)

        - Perfect chirp sonar target. (John Goff)
    - Water column effects complex in this region
    - Possible link with off shelf sub-experiment
    - Objectives : Dispersion, propagation, TL, reverb, characterization

- West Florida sand shelf (100-150 m of water) in the general area of the Area Characterization Test I experiment
    - Area already has some ground truth, possibility that area could be surveyed during the time frame of the Panama City survey
    - Strong current system after shelf break
    - Strong water column stratification near shore
    - Benign relative to New Jersey site.
    - Some internal wave activity

- North of Scripps Pier (2)
    - Medium Sand over bed rock (10 m below) Range independent normal to the coast and range dependent parallel to the coast as bedrock layer rises.
    - Problem with California environment laws?

- Barents Sea (3)
    - Thin layer of soft sediment over hard bottom
    - Possible collaboration with Norway
    - Weak flow areas available
    - 180m water depth
    - High energy environment along slope but quiescent environment on shelf

- Georges Bank – (4)
    - Rough hard bottom
    - Sensitive fishing area
    - Sensitive environment
    - Strong tides

- NURC sites:
    - Mae and Kyle can collaborate with us.
    - ITAR Issues

II.B. Assets from PIs for sea bed characterization experiments:

- Peter Dahl
    - MORAY System – short HLA and VLA with some vector sensors
    - 1-2 directional wave buoys
    - 2-20 kHz sources

- George Frisk

    - 4 MOMAX drifters

- Bill Hodgkiss
    - 2 - 16 element VLA
    - 2 - 8 element source/receiver arrays (10-32 kHz)
    - Towed source system (rented J15)
    - 1 – 10 kHz additional sources (ITC 2015)

- Mike Buckingham
    - 2-2015 ITC Sources
    - Sing Around sound velocity Device; (deep noise instrument)

- APL-UW
    - 2-2015 towed sources (2.5 – 10 kHz)
    - SAMs (good to 100 m depth)
    - 32 element VLA (3.5 kHz)
    - IMP Roughness measurement system with laser line scan
    - Seabirds Array CTD chain in range and depth
    - Underwater rail system with source and receivers (shallow water only)

- APL (Orest Diachok)
    - Station keeping buoy
    - Ultra broadband source (200 Hz – 10 kHz)

- ARL-UT (Isakson)
    - ROV with laser line scan system and normal reflection loss from 5 -80 kHz

- Jim Miller
    - Geophone Array (GeoJim)
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- Thermister Strings from various places
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- Frank Henyey
    - 50 CTD chains that can be deployed from buoys
- ESL ARL:UT David Knobles and Preston Wilson
    - 2 L-shaped SWAMI array,
    - DOOS: 100 element vertical line array or horizontal line array shallow or deep,
    - EDOOS: VLA (up to 6 km deployment depth), 180 elements some vector
    - David Knobles' volumetric array
    - J15 and CSS
    - Artificial Fish School
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II.C. Ground truth characterization requirements:

- Chirp sonar for layering
- Sediment material characterization of sea floor
    - Grab
    - Vibracore (2-4 m)
    - Slow Core
- Core Measurements
    - Density (gamma ray)
    - Porosity (resistivity)
    - Grain size distribution

- Core logger and micro CT from NRL (Alan Reid, Mike Richardson)
- Roughness characterization along track (ROV laser line scan system)
- AUV with towed array NURC with SLITA Array
- Diver cores, and grab samples, stereo photography in shallow water (Panama City site)
- Sub-bottom inhomogeneities?

III. General ideas for the experiment plan

The experimental designs that were discussed for geoacoustic characterization were conceptually simple:

- Repeated runs along track between deployed receiver arrays (bottom moored horizontal and vertical hydrophone arrays) with sound sources of different modes (CW, LFM) to cover a broad band of frequency from 25-20000 Hz.
- Persistent measurements at fixed locations are also necessary to provide solution statistics.
- Need to design experimental geometries that avoid effects of the water column variability, or devise means to account for the variability in interpreting the data. This points out the need for simultaneous measurements of water column sound speed profiles with towed thermistor strings, AUVs, gliders or otherwise.
- Experiments at both short ranges (1-3 water depths) and long ranges (> 15-20 water depths) should be planned over the track. The track line should extend to distances of at least 25 km.
- Strong support for experiments at sites with different sediment types. One option that was discussed in relation to the NJ shelf area was to re-visit the MORAY outer shelf wedge site from SW06, combined with a deployment at the mud patch site (John Goff) near Martha's Vineyard. The distance between these sites is not great, so 4-5 day deployments at each area are possible on the same cruise
- Direct measurements of sediment properties by experiments with the most recent version of the SAMS apparatus should be made at the sites. The direct measurements are complementary to the geoacoustic characterization experiments.

Use of new approaches to data acquisition was enthusiastically supported:

- Drifting VLA for ambient noise geoacoustic inversion
- AUV with sources and towed array
- ROV with laser scanner and vertical sonar

Summary and Strawman Plan for sea bed characterization experiment

The experiments in geoacoustic characterization should be designed to address the following:

- Determine the dispersion of sound speed and attenuation in sediment materials of different types: sand; silty-sand-clay; mud.
- Dispersion analysis involves measurement of attenuation (and sound speed) vs frequency over a frequency band from 25 Hz to 20 kHz.
- Investigate the impact of sub-bottom layering and the range dependence of the sub-bottom structure.
- Characterize the elastic properties of the sediment, and determine the effect of shear wave propagation in the bottom on the sound field in the water.
- Experimental geometry is important: need to design experiments at short ranges (1-3 water depths) as well as long range experiments (> 15-20 water depths). This appears to be especially important for the measurements of attenuation or effective attenuation. Repeated runs over the same track are essential to provide statistics of the distributions of estimated model parameters.
- Measurements of spatial (vertical and horizontal) and temporal coherence.
- The vector properties of the acoustic field need to be explored. Experiments should also focus on the impact of the environment on the vector field and its coherence.
- Higher frequency is important: > 500 Hz. Inversion methods for sea bed characterization should be applied to data from experiments at higher frequencies.
- This opens up a new issue of performance of the inversion methods at higher frequencies: sea bed roughness (and sub-bottom layer roughness) will have to be measured in ground truth and taken into account in the inversions
- Use of moving sources and receivers in design of experiments to characterize the bottom.

Ground truth of the sea bed and sub-bottom structure is essential. Use of new systems such as the ROV laser scanner and impedance profiler can complement the conventional ground truth methods of chirp sonar survey and physical property analysis, particularly in making measurements along the experimental tracks.

Justification for the experiments

There are two sore points that arise as challenging questions about the experiments that were discussed.

1. Why are we still designing experiments to address the same science questions that were identified previously in other workshops to define the knowledge gaps in shallow water acoustics?
2. Why are we proposing to return to the same site off New Jersey . This question is related to the same questions that were asked in the other breakout group.

The second question is easier to address. Certainly, one of the products of the research is the transition of effective methods for rapid environmental assessment to agencies such as NAVOCEANO. The methods for estimating sea bottom parameters must be effective in different types of sea bottoms, from sand to silt and mud. Our work at the New Jersey site provides two of the basic types near the SW06 experiment site. And from the discussions at the working group, a new silty-mud site was suggested by John Goff that is also in the close vicinity. The planned research for the New Jersey area allows this research to continue.
A second reason for the New Jersey site is related to the science question about the transition from shallow to deep water. The shelf break sites at New Jersey provide easy access to sloping bottom environments. It may make sense to link the sea bottom objectives and the 3D objectives in a single experiment at New Jersey.

For the former question, we can say that our experimental work over the last decade or so has convinced most of us that the product of inversion algorithms must be presented in terms of probabilities of environmental parameter values. The experiments that we do today are designed to provide this type of output for quantities such as sediment sound speed versus depth. Coupled with this is the realization that the greatest uncertainty in many cases is in the water column sound speed. The impact of errors in the water column on geoacoustic model parameter estimates is an unsolved issue from SW06, and it continues to influence design of experiments.

Finally, there was significant discussion about the need to have a Navy relevant part of the experiment clearly stated. A few amateur comments. The experiment that we propose is basic research. However, if we can connect the research to a few areas of signal processing, this may be helpful. In short how could the knowledge that we propose to gain about the seabed enhance sonar signal processing methods of interest? Some folks in the signal processing world say that the nature of the seabed is not relevant. Can we prove them wrong? This is in some sense an old question, especially as in regards to matched-field processing and beamforming. It is also intimately linked to the issue of array coherence. Further, in recent times there has been significant interest in not just geoacoustic inversion solutions, but also inversion for the probability distributions of both seabed and experimental parameters. The relationship between statistical variability obtained from experimental data and the actual variability of the seabed is not understood. How could the statistics extracted from both the acoustical and physical measurements that we make assist in ideas on how to better incorporate statistics and probability into sonar signal processing?