Proceedings, ONR Shallow Water Acoustics 2006 Workshop
Applied Physics Laboratory, University of Washington
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Table of Contents

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I. Introduction

The Ocean Acoustics Code, Office of Naval Research, sponsored a two-day workshop on shallow water acoustics. The primary purpose of the workshop was to define and identify key basic research problems to be addressed in a field experiment to be conducted in fiscal year 2006. Seventeen scientists attended the workshop. In addition, several researchers contributed poster presentations. A list of attendees and the workshop agenda are given in Appendix I. Poster titles and contributors can be found in Appendix II. The presentations given by the attending scientists have been copied to a CD and delivered to ONR program managers. They are also included in this CD-R report distribution.

The major conclusions of the workshop are:

- There are three interconnected components to be addressed in the FY06 experiment. They are (1) clutter physics (fish and geo clutter), (2) mid-frequency acoustics (1–10 kHz), and (3) low-frequency acoustics (10–1000 Hz).
- A field experiment site off the coast of New Jersey was chosen; extensive environmental data already exist and it is best suited to take advantage of the synergy among all three components. There is also the opinion that soft sediments made of mud deserve investigation. A collective decision was made to concentrate on the New Jersey site for the FY06 effort.
- In order to investigate physical mechanisms governing various acoustic processes, detailed environmental data will be measured in a small area using *in situ* and various acoustic and non-acoustic techniques. These environmental data will be used to model mid-frequency acoustics and to calibrate inversion results in a larger area and along different tracks using remote sensing methods to accommodate the environmental parameter requirement for low-frequency and clutter components.
- Several working groups were formed (Appendix III) and a second workshop will be held. The goal for the second workshop and the working groups is to make detailed plans for the experiment.

II. Background

In shallow water regions (typically shallower than 200 m) the performance of many sonar systems is strongly influenced by the variables of the bottom, surface, and the water column, including the influence of biomass in the water column. Because such variables can significantly affect propagation, target detection, localization and classification, and underwater communication, it is essential to know the various mechanisms governing these acoustic interactions with the water column and the boundaries to understand and accurately predict sonar performance in shallow water. To gain quantitative understanding of how sound interacts with the boundaries and volume, it is also essential to measure all relevant environmental parameters at sufficient spatial and temporal resolutions. The experiment must be designed carefully to elucidate physical mechanisms, and provide data and models that can be used to address U.S. Navy questions.

III. Overall scientific goals

Because a central problem in studying shallow water acoustics problems is how to deal with environmental uncertainties, our long term goals are: *to determine the dominant physical processes that affect Navy sonar system performance and to develop decision making tools for use in shallow water environments. This will include determination of how to choose the relevant environmental parameters to measure, how often to measure them, and how to best select sonar frequencies.*

For the FY06 experiment the basic research (6.1) questions of most practical value to the Navy are: *What are the primary physical mechanisms driving sonar performance in the littoral region? What is the relative importance of the various environmental influences on predictions of propagation, target scattering, reverberation, and clutter? How do these vary as a function of controllable variables such as frequency and measurement geometry?*

While there are several science questions that will be addressed in the FY06 experiment, here we list only one major science goal for each of the three components. The achievement of these goals should be a measure of the success of the project. The inter-dependence of the science issues among the three components will also be discussed in this section. A more complete list of science issues will be given in a later section.

<u>Clutter component:</u>
Acoustic clutter is one of the primary problems encountered by active sonar systems operating in continental shelf environments. Clutter is defined as those returns from the environment that stand prominently above the diffuse and temporally decaying reverberation background; they can be confused with or camouflage returns from an intended target such as an underwater vehicle.

The goal of the clutter component of SW06 is to determine and understand the physical mechanisms that govern clutter well enough to develop clutter mitigating and exploiting technologies that will significantly enhance the Navy's tactical decision making ability and active sonar operations in continental shelf environments. This goal has been given a very focused new direction by results of the Acoustic Clutter (Geoclutter) Program, which has shown that densely populated fish schools may be the dominant cause of clutter in many continental shelf environments. It is strongly recommended that this clutter component be conducted at the NJ Strataform site in conjunction with the low- and mid-frequency components of SW06 because (1) bioclutter has been consistently found to be pervasive there over two consecutive field experiments (the greatest clutter and biomass congregate near the shelf break, which is of prime importance to the low-frequency component of SW06); (2) the seafloor and sub-bottom have been surveyed extensively and are well characterized; (3) the oceanography is well understood; (4) the site is easily accessible and it is relatively inexpensive to operate there; (5) numerous synergies exist with the low- and mid-frequency components of SW06 in scientific objectives, environmental support, equipment, and personnel that are unique to the New Jersey Strataform site.

Mid-frequency component (1–10 kHz):
Because of the complexity of shallow water environments, insufficient measurements of environmental parameters have often prevented definitive model/data comparisons on mid-frequency propagation and scattering tests. In the SW06 experiment we will measure environmental parameters of the sea surface, bottom, and water column, along with their variabilities, with sufficient resolution. Both *in situ* measurements and inversion methods will be used.

These measurements will facilitate achieving two unique goals: the first is to collect direct-path forward and backscatter data from the boundaries and the water column and make detailed model/data comparisons constrained by the measured environmental parameters. This will enable unambiguous predictions on dominant scattering mechanisms from the boundaries as well as from internal waves of the volume. The second is to definitively evaluate various remote sensing methods that invert for sediment properties. There exist several methods make such inversions. One is chirp sonar data inversion, another is inversion by measuring bottom loss, and a third is using ambient noise data to invert for mean bottom properties. These inversion methods can be used to survey large areas, therefore providing a practical way to acquire environmental data. However, these methods need to be validated and their errors assessed. Detailed environmental measurements in one area, where inversion methods are also applied, will make possible the evaluation of the inversion methods. When the inversion methods are validated in this manner, they can be applied to large areas for both low- and mid-frequency applications.

Low-frequency component (10–1000 Hz):
A major thrust in low-frequency shallow water research has been to understand the intensity fluctuations in shallow water. These fluctuations are a function of both range and azimuth in an anisotropic waveguide. A major source of anisotropy on continental shelves is the internal wave field, particularly the nonlinear internal wave field. Most experimental efforts to date have concentrated on across-shelf propagation, including the NRL effort in fall 2003 at the New Jersey site. However, both calculations and our SWARM data have shown that, due to the focusing effects of internal waves on along-crest acoustic propagation, there could be much more significant fluctuations in that geometry. Our major goal is to understand intensity fluctuations versus range, frequency, and azimuth in shallow water. We would propose having a major component of this experiment focus on the along-shelf geometry that has largely been ignored, at least experimentally. This issue of scattering from non-linear waves can be properly addressed at the New Jersey site.

IV. Relation among the components

The central goal for all three components is clearly shared and is to improve sonar performance in littoral seas. Given this, the workshop also concluded that there is a high level of synergy among the three components, and that an experiment involving all three together will benefit from the collaborative effort in many ways. Great savings in cost and effort can be achieved because many of the experiments in the three areas require similar equipment, environmental support measurements, and data reduction techniques. The primary findings of one component, for example, will typically provide important supporting information to the other components. Additionally, collaboration among scientists in the various components will lead to a far greater exchange of ideas, techniques, and overall progress.

To best utilize resources, an imbedding scheme will be adopted for the experiment layout. A center site near the shelf break at 80-m water depth has been chosen where most of the mid-frequency work and some of the clutter and low-frequency work will be done. From here detailed environmental measurements will be taken. A 30-km track toward shore and a similar track parallel to shore will be surveyed by remote sensing techniques such as chirp sonar. The remote sensing results will be calibrated by the detailed environmental measurements at the center site. Clutter and low-frequency measurements will be conducted along these tracks. The tracks have been chosen to be near the shelf break where there is frequent fish activity, a good location to address bioclutter problems.

V. Detailed science issues for the clutter component

Acoustic clutter is one of the primary problems encountered by the Navy's active sonar systems operating in continental shelf environments. Clutter is defined as those returns from the environment that stand prominently above the diffuse and temporally decaying reverberation background; they can be confused with or camouflage returns from an intended target such as an underwater vehicle. The goal of the clutter component of SW06 is to determine and understand the physical mechanisms that govern clutter well enough to develop clutter mitigating and exploiting technologies that will significantly enhance the Navy's tactical decision making ability and active sonar operations in continental shelf environments.

The approach is to analyze experimental field data by using and developing the most essential models of clutter, acoustic reverberation, and target scattering necessary to make active sonar systems perform effectively in clutter-infested environments. Under the Acoustic Clutter Program, formerly the Geologic Clutter Program, the Acoustic Clutter Reconnaissance Experiment (ARE) 2001 was primarily aimed at and was successful in establishing the presence and persistence of acoustic clutter off the New Jersey continental shelf, an area that has little or no bathymetric relief. Measurements of clutter in such areas have been a problem for naval operations because clutter has not been linked successfully to fixed environmental features such as seafloor geology and is therefore difficult to predict. It was hypothesized that sub-seafloor geology might cause clutter, given the abundance of sub-seafloor geologic features in many continental shelf environments. Such sub-bottom features were carefully mapped in the New Jersey Strataform area before and during the Acoustic Clutter Program. The Main Acoustics Experiment (MAE) of 2003 was designed to be more controlled than ARE, and was able to establish the primary mechanisms for the observed clutter; biology, i.e., dense fish schools, was found to be the dominant cause. The experiment equipment (source, receivers, targets) had precise calibration so that theories and models could be tested accurately. Sophisticated waveguide scattering models, simulations and statistical studies, as opposed to simple sonar-equation-based models, were essential for directing experiment design and supporting the analysis and interpretation of experiment results. Waveguide modeling is necessary due to the pervasiveness of multipath and multimodal propagation and scattering effects in continental shelf environments.

The objectives of SW06 are to build on the definitive results of ARE 2001 and MAE 2003, which show fish schools to be a dominant cause of clutter and show no noticeable sub-bottom mechanism for clutter to date. (Certain bathymetric features, typically with higher slopes, were shown to cause clutter during ARE, MAE, and previous experiments.) With these results providing a clear direction, it is now possible to probe deeply enough into the physical mechanisms and characteristics of clutter that physics-based clutter mitigation and exploitation technologies may be developed. In this context, three primary objectives emerge for the clutter physics component of SW06. Under these objectives are listed a set of experimental investigations deemed necessary to fulfill the specific objective.

<u>Objective 1</u>: Determine and quantify the processes that cause clutter to evolve in time and space. Once the processes that cause the temporal and spatial evolution of clutter are understood, methods for mitigating clutter or tactically exploiting it may be developed.

Investigations:

1. Determine the long-term correlation of acoustic clutter with fish concentration at a site of consistently repeatable fish clutter with focus on the motion and evolution of target-like clusters
2. Correlate remotely measured fish school clustering behavior with geology and oceanography
3. Characterize the fish school species that cause target-like clutter
4. Develop methods to experimentally invert clutter for spatial fish school concentrations from remote active sonar measurements
5. Determine the extent to which oceanographic variations cause target-like clutter in the absence of fish

<u>Objective 2</u>: Determine when and why evolving clutter is indistinguishable or distinguishable from intended targets. This is again clearly aimed at finding avenues ripe for the development of clutter mitigation or tactical exploitation technologies.

Investigations:
1. Determine the range and azimuth dependence of scattering from fish schools
2. Determine the frequency dependence of scattering from fish schools
3. Determine the Doppler shift and spread caused by scattering from fish schools
4. Characterize spatial and temporal evolution characteristics of target-like clutter to enable classification, which goes back to Objective 1

<u>Objective 3</u>: Determine the extent to which diffuse reverberation evolves in both time and space and the causes for this evolution, and whether it is related to the evolution of clutter. Both intended targets and clutter eventually disappear into the diffuse background reverberation as the range of the target increases or resolution of the active sonar decreases. The causes of diffuse reverberation are still not clear, especially in areas of high bioclutter, and so the primary physics governing active sonar performance is not yet clear. The investigations noted below are intended to elucidate the physics to the point that it can be exploited for sonar performance improvement.

Investigations:
1. Determine the extent to which evolving diffuse reverberation is caused by volume scattering from fish schools or other water column mechanisms
2. Determine the extent to which evolving diffuse reverberation is related to coupled oceanographic and geologic scattering processes
3. Determine the extent to which diffuse reverberation is caused by boundaries verses volume scattering

<u>Objective 4</u>: Determine the spatial and temporal characteristics of scattering from fixed deterministic targets in a continental shelf environment. As part of the Acoustic Clutter Program, we have shown, first with theory and then with field data, that the standard sonar equation is typically in error by tens of dB in predicting even simple target return levels in continental shelf environments. This is because propagation and scattering are convolved due to multipath or multimodal effects in these environments. This problem has been realized empirically in Fleet operations, but has never been addressed in operational systems, and can lead to huge errors in target detection, localization, and classification. An understanding of the degree of accuracy to which target levels can be measured from a calibrated target in a waveguide is essential before the clutter caused by random environmental targets can be properly understood.

Investigations:
1. Measure the scattered levels as a function of frequency and range from fixed calibrated targets deployed in the water column and on the seafloor
2. Repeat (1) over time to study the temporal statistics of returns due to environmental and other fluctuations

<u>Assets and synergies:</u>
The two cruise reports from ACRE 2001 and MAE 2003 show how these major offshore experiments were conducted effectively and efficiently at extremely low cost by carefully selecting, developing, and nurturing key equipment, personnel, software systems,

organizations, and their collaborative links. All mechanisms and expertise still exist and are in place for another experiment but will likely slowly disappear as time passes and these assets are not coordinated or used.

The essential measurements will require the ONR FORA horizontal receiver array and the MACE source array, which must be moored for effective use. Each will require a medium sized to large research vessel. It is advisable to have at least three environmental moorings available, with two deployable on the fly as necessary during the experiment. One mooring is left from MAE 2003. A third vessel of at least *Cape Henelopen* size will be required for concurrent local fish density and oceanographic CTD measurements. Trawling for fish species should also be conducted and possibly coordinated with NMFS to conclusively identify the fish species. Many of the environmental support measurements needed as well as the primary source receiver assets are similar to those of the mid- and low-frequency components. The clutter measurements are in the low- to mid- frequency regime and are subject to all the issues involved with low- to mid-frequency acoustics of these other two components, so a potential for great synergy exists.

Because the low- to mid-frequency systems used to actively probe clutter enable continuous, instantaneous remote imaging over hundreds of square kilometers, it is not necessary to 'chase fish' in the manner done by traditional high-frequency fish-finding sonar. A properly designed experiment with the FORA receiver and MACE source positioned within tens of kilometers of major and minor fish schools would be sufficient to accomplish the experimental goals. Only the smaller *Cape Henelopen* vessel would be required to 'chase fish,' and because the fish tend to follow oceanography, sampling the two together will lead to significant synergies.

VI. Detailed science issues for the mid-frequency component

This section outlines a plan for a mid-frequency shallow water acoustics experiment to be conducted in FY2006. The general goal is to improve our understanding of sound propagation and scattering in a complicated shallow water environment (depths of order 100 m). The sound frequency considered is in the range of 1–10 kHz. The mid-frequency experiment will focus on localized areas where detailed environmental measurements will be made in order to make model/data comparisons of the acoustic field following one or more interactions with the interface.

Background:

Many practical sonar systems operate in the frequency band 1–10 kHz. In shallow water regions (typically 100–200 m depths) the performance of such systems is strongly influenced by the presence of the bottom and surface. Because the bottom and surface scatter, refract, and attenuate sound, knowing the various mechanisms governing these acoustic interactions with the boundaries and volume is essential to accurately simulate sonar performance in shallow water. To gain quantitative understanding of how sound interacts with the boundaries and the volume, it is also essential to measure all relevant environmental parameters at sufficient spatial and temporal resolutions. Making such measurements properly and combining them in modeling efforts with acoustics measurements provides the opportunity to quantitatively understand the various processes involved in shallow water acoustics.

Approach:
Starting with assumptions and hypotheses based on current knowledge of the field, we will combine acoustics measurements with modeling efforts using the measured environmental parameters to achieve quantitative model/data comparisons of sound fields interacting with bottom, surface, and the water column. Similar to the approach used in the ASIAEX East China Sea program, we will start from a local area on the order of 100 m by 100 m, and study single interactions of sound with the bottom and the surface as well as the water volume over space and time. In each case, we will make detailed model/data comparisons. We will also investigate multiple (2–3 bounces) interactions of sound field with the bottom and surface. The point here is to combine the modeling results for single interaction into a model for multiple interactions. Finally, we will study long-range propagation, multiple forward scattering, and reverberation issues over a range of 10–20 km. By necessity, the experiment will consist of an acoustics part and an environmental measurement part. We will emphasize carrying out environmental measurements at sufficient resolution to properly answer the acoustic issues to be addressed. The acoustics topics include:

1. Single boundary interaction backscattering (surface and bottom)—what are the most important physical mechanisms?
2. Single boundary interaction and volume (internal waves) forward reflection and forward scattering—what are the most important physical mechanisms?
3. Multiple boundary interactions—Can we successfully combine our knowledge of single interactions to predict the results of a small number of surface, bottom, and volume interactions?
4. Long-range (10–20 km) propagation and reverberation—Can multiple interactions with rough boundaries and the volume actually simplify the field at long ranges?

Environmental measurement topics will include *in situ* and remote sensing components. They are:

1. In-sediment measurements of sound speed in the bottom over a depth of 3–5 m with spatial resolution of 10 cm in both vertical and horizontal dimensions.
2. *In situ* measurements of bottom roughness over several meters with horizontal spatial resolution of 1–2 cm.
3. *In situ* measurements of sea surface roughness spectra and wind speed
4. Internal wave measurement using a CTD chain vs. time and space
5. Acquisition and analysis of cores to obtain sediment density, attenuation coefficient, and sound speed
6. Remote sensing using chirp sonar to estimate sediment geo-acoustic properties over large areas
7. Remote sensing of geo-acoustic parameters using ambient noise

8. Remote sensing of bottom topography data over large areas using side-scan multi-beam sonar

In addition, we will investigate how to estimate key environmental parameters using only acoustic fields from reflection and backscatter. This will be accomplished by optimizing forward model parameters with acoustic data.

<u>Science issues:</u>
The environmental measurements of the bottom interface roughness and sub-bottom layering and heterogeneity will be used to predict bottom forward scatter and backscatter, as a continuation of the ASIAEX East China Sea effort. In that experiment, we successfully measured bottom roughness and sub-bottom heterogeneity as well as mid-frequency bottom backscatter. We established that bottom roughness caused by bottom biological activity is the dominant scattering mechanism. This proposed experiment will be conducted at a site where the bottom is made of medium-fine sand with possible sub-bottom silt layers (different than the East China Sea site where consistent fine sands made up the top 5 m of sediments). The main goal is to determine the dominant causes of bottom scattering. In addition, we will also study the forward scatter and reflection problem. This will form part of the basis for understanding multi-bounce problems. Again, a key element of this study is to have sufficient environmental measurements to interpret the acoustic measurements.

The sea surface roughness spectra, combined with spectral models at high wavenumber, will be measured to predict surface forward scatter, surface backscatter, and the spatial coherence of the field following a surface interaction. The backscatter measurements will be an addition to what was done in ASIAEX. In addition, the impact of bubbles and bubble clouds near the surface on forward scatter and backscatter will be considered.

Acoustic propagation measurements will be made that include several interactions with the sea bottom and surface. We will use these results to test models that combine the single boundary and volume interaction models. For this part of the experiment, wavelength scale environmental data will only be available at selected points. As a result, it will be necessary to extrapolate the environmental data to larger areas assuming statistical homogeneity.

Long-range (10–20 km) propagation and reverberation will also be measured. This part of the work will be a collaboration with the low-frequency component of the project. The hypothesis to be tested is that at long ranges, the acoustic field becomes increasingly coherent due to mode stripping by surface and bottom scatter. Specifically, waves propagating at larger grazing angles suffer greater scattering by the interfaces. A portion of this energy is scattered to high angles, and is then lost into the bottom. Therefore, at long range, the surviving waves are those propagating at very small grazing angles, which are not prone to scattering. As a result, the field is increasingly more coherent with range.

Remote sensing issues:
The most difficult problem in conducting mid-frequency acoustics basic research is obtaining environmental characterization at the appropriate spatial resolution. This is especially so when dealing with sea bottom problems. While it is possible, with sufficient resources, to collect ground truth data through *in situ* bottom measurements such as in-sediment tomography, this approach cannot be used for large areas. Therefore, it is necessary to rely on remote sensing techniques to invert for geo-acoustic parameters. The key issue here is to validate the inversions with sufficient confidence and to thoroughly investigate errors and uncertainties of the inversions. In this experiment, two remote sensing techniques will be investigated: chirp sonar inversion, and geoacoustic inversion using ambient noise. In addition, as mentioned earlier, inversion through optimizing forward acoustic models using reflection and backscattering data will be studied.

Chirp sonar has the advantage of covering large areas in a manageable time. Most of the applications of chirp sonar have been for survey purposes. In recent years inversion algorithms have been developed to use chirp sonar data to estimate geo-acoustic parameters. However, the inversion techniques and results have not been validated with data; hence questions remain as to the accuracy and uncertainty of the inversion results. In this experiment, we will conduct *in situ* measurements of geo-acoustic parameters with fine resolution using tomographic methods. Chirp sonar data will be collected over the same regions where *in situ* data are available. Thus inversion methods using chirp sonar data can be examined at those regions and can potentially be extended to other areas where *in situ* data are not available. In this effort, in addition to field measurements and development of inversion algorithms, a forward model needs to be developed to simulate the chirp sonar sound field backscattered from a seafloor with known bottom properties.

During ASIAEX a proof of concept experiment indicated that noise measured on a vertical array can be used to conveniently and reliably estimate bottom properties. In the proposed experiment, with more geo-acoustic ground truth data, we intend to test the approach under different conditions, and emphasize the error analysis so that the methodology can be integrated into applications. This method can provide mean geo-acoustic properties of sediments, which are of importance to propagation and forward scatter, as well as to backscatter.

In summary, the mid-frequency field project will emphasize environmental measurements and model/data comparisons in order to understand mechanisms of sound scattering and propagation in shallow water environments. The approach is to start from local areas and study single interactions with interfaces and, in a step-by-step fashion, extend to several interactions with interfaces, and eventually to long-range scenarios. Remote sensing techniques will be developed and examined to explore their potential to collect geo-acoustic parameters over large areas.

VII. Detailed science issues for the low-frequency component

Acoustics

1. *Intensity fluctuations*. A major thrust in low-frequency shallow water research has been to understand the intensity fluctuations in shallow water. These fluctuations are a function of both range and azimuth in an anisotropic waveguide. A major source of anisotropy on continental shelves is the internal wave field, particularly the nonlinear internal wave field. Most of our experimental efforts to date have concentrated on across-shelf propagation, including the NRL effort in fall 2003 at the New Jersey site. However, both calculations and our SWARM data have shown that, due to the focusing effects of internal waves on along-crest acoustic propagation, there could be more significant fluctuations in that geometry. We thus feel that it is scientifically important to understand intensity fluctuations versus range, frequency, and azimuth in shallow water. We would propose having a major component of this experiment focus on the along-shelf geometry that has largely been ignored, at least experimentally. This nonlinear scattering issue is best addressed at the New Jersey site.

2. *Acoustic coherence*. In ASIAEX South China Sea, we were able to deploy a horizontal line array along with the standard vertical line array to study transverse horizontal and vertical array coherence issues at a site that was very well characterized environmentally. We advocate extending this work, as it appears that we are on the verge of understanding in detail how the environment creates the horizontal array coherence lengths seen, such as Carey's 30 lambda "rule of thumb" number. A yet underexplored (in terms of measurements) issue is coherence in the along-shelf direction in the presence of nonlinear internal waves. Computer calculations indicate that this is a substantial issue. (This task derives from the same scattering physics as the issue of intensity fluctuations mentioned above, but is focused on a different acoustic variable. In particular, the horizontal coherence depends most critically on phase variability, whereas the above task concentrates solely on amplitude effects.) Another very interesting research issue is the "water column dominance" of the horizontal coherence and how it affects the vertical coherence—a recent theoretical result of importance that should be examined experimentally.

3. *Bottom interaction studies*. There are numerous shallow seabed issues that are of current interest, for instance: a) the frequency dependence of the bottom attenuation at low frequencies, b) the effects of internal waves on bottom inversions, especially those using pressure as a function of range as input data, and c) new methods of inversion, including the waveguide invariant methods. These questions can probably be addressed at either shallow water site. A careful measurement of propagation loss vs. range over the 50–1500-Hz interval, combined with independent assessments of the geoacoustic parameters, would provide a very useful underpinning for this work, and also tie it firmly to standard Navy methods.

4. *Efficacy of synthetic aperture array methods*. This is both an acoustic propagation/scattering issue and a signal processing issue. The results may be different for different sites due to the different oceanographic and geological environments.

5. *Coherence seen in towed vs. fixed horizontal arrays*. The difference between moving and fixed geometries is of great interest, and indeed with the ONR Five Octave Research Array (FORA) and the fixed arrays available (e.g., the WHOI array and SGAMS), we can examine the differences observed. A concern with this is that we will focus more on "array element localization" errors than environmental and motional effects. A further worry is the noise radiated by the tow ship, which has plagued previous comparisons between fixed and moving systems.

6. *Predictability*. Given the Uncertainty DRI's emphasis on quantifying the performance of sonars, this well constrained experiment could give us a chance to look at some of the algorithms being developed. Both sites would be acceptable for such work. We note that predicting the mean TL hinges mostly on bottom knowledge, predicting the amplitude fluctuations requires both bottom and water column knowledge, and predicting the horizontal array coherence seems to be tied most closely to water column correlation scales.

7. *Acomms*. While we have done much work in mid-frequency Acomms, we have done very little at low frequencies. The PRC has obtained some rather nice experimental results in shallow water, low-frequency Acomms, and this experiment would give the U.S. a chance to develop some expertise in this area. Mid-frequency Acomms could be addressed simultaneously. The "single path" experiments that the mid-frequency program is looking to perform are intimately tied to this objective as well.

8. *Ambient noise*. The noise field at the receiver is an important quantity for sonar performance, and its effective cancellation (e.g., via adaptive methods) is still an important research issue. A vertical and horizontal noise collection system could be deployed near the active measurement site, giving "uncontaminated" noise measurements as a function of environmental parameters. The noise at the New Jersey site is expected to be dominated by natural noise rather than shipping noise.

<u>Physical Oceanography</u>:

1. *Higher frequency oceanography fluctuation spectrum*. The scattering of sound by the water column at low- to mid-frequencies depends in part on the ocean fluctuation spectrum. This spectrum is comparatively poorly known for shallow water, and this experiment would give us a chance to make some good measurements of it. Indeed, for many of the acoustics applications noted above, such measurements would be a necessity.

2. *Non-linear internal wave horizontal coherence scales*. Much calculation has been done examining along-soliton-crest acoustic propagation, invariably using a very long-to-infinite IW correlation length. However, SAR images show that the along-crest correlation scale is finite. We need to quantify this scale with subsurface measurements, as the SAR surface picture is somewhat biased (i.e., does not reflect the subsurface situation, which is what we need for acoustics.)

3. *Other background PO measurements*. Possibilities include waverider buoys, Sea Soar (great, but expensive), CTDs, moored CMs, Sea Cats, P-sensors and T-strings, satellite SAR and AVHRR. Ocean numerical models also might be useful, and in fact the Rutgers group (Haidvogel *et al*.) have regional models available for the New Jersey site. These PO models can drive sediment transport/bottom ripple models, which can be used to predict and understand the bottom microtopography of importance to reverberation.

Marine Geology:

Background measurements needed. While there do not seem to be any obvious first order geology issues here that have not been addressed by STRATAFORM, LEO-15, and other programs, there will be a need for adequate background measurements, especially at the source and receiver sites. These include: 1) cores to obtain material properties, 2) chirp sonar/3.5-kHz vertical profiling to obtain both layering and attenuation, and 3) sidescan sonar imaging to obtain bottom roughness. It should be noted that: 1) many of these measurements already exist at the New Jersey site due to other experiments and advanced surveys and should be exploited to reduce expense, and 2) the bottom interaction studies noted above are in addition to these "standard surveys."

Appendix I. Workshop attendees and agenda

<u>Agenda</u>

Wednesday, 9/25/2003

8:00 - 9:00, breakfast
9:00 - 9:15, welcome and ONR introduction by Ellen Livingston
9:15 - 9:55, Jim Lynch, overview of low-frequency shallow water acoustics
9:55- 10:35, Nick Makris, overview of clutter acoustics
10:35 - 10:45, break
10:45 - 11:25, DJ Tang, overview of Mid-frequency acoustics
11:25 - 11:40, Peter Dahl
11:40 - 11:55, Glen Gawarkiwicz
11:55- 1:00, lunch and posters

1:00 - 1:15, Luis Souza
1:15 - 1:30, David Knobles
1:30 - 1:45, Ross Chapman
1:45 - 2:00, Ching-Sang Chiu
2:00 - 2:15, Harry DeFerrari
2:15 - 2:30, Bill Hodgkiss
2:30 - 2:45, Charles Holland

2:45 - 3:00, break
3:00 - 3:15, John Goff
3:15 - 3:30, John Perkins
3:30 - 3:45, Frank Henyey
3:45 - 4:00, Kevin Williams
4:00 - 4:15, Eric Thorsos
4:15 - 5:00, Posters
5:00 - 5:30, summary of first day

6:00 - 7:30, reception

Thursday, 9/26/2003

8:00 - 9:00 breakfast
9:00 - 10:30, presentations of strawman experiment plans for the three focus areas
10:30 - 12:00, discussion
12:00 - 1:00, lunch

1:00 - end, update to experiment plans

Appendix II. Poster contributors

M. Badiey, B. Katsnelson, J. Lynch, and W. Siegmann, “Measurement and modeling broadband acoustic signals through shallow water internal waves”

A. Ivakin, D. Jackson, and D. Tang, “Identifying seabed scattering mechanism using vertical linear array”

J. Preston, “The ONR OCTAVE research array (FORA) at Penn State”

D. Rouseff and A. Turgut, “Horizontal array beamforming using the waveguide invariant”

J. Preisig, “Research questions for FY06 shallow water experiment”

K. Becker and S. Rajan, “Low-frequency shallow water experiment 2006”

K. Becker, “Modal group velocity estimates from a single hydrophone for a point-source moving with constant velocity”

J. Miller and G. Potty, “Long-range sediment tomography”

Appendix III. Working groups

Oceanography:
Frank Henyey, Jim Lynch, Glen Gawarkiwicz, and Ching-Sang Chiu

Geophysics and Geology:
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Biology:
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Acoustic Sources:
Jim Lynch, Nick Makris, Peter Dahl, Harry DeFerrari, John Preston, Bill Hodgkiss, and David Knobles

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The Ocean Acoustics Code, Office of Naval Research, sponsored a two-day workshop on shallow water acoustics. The primary purpose of the workshop was to define and identify key basic research problems to be addressed in a field experiment to be conducted in fiscal year 2006. Seventeen scientists attended the workshop. Several researchers contributed poster presentations as well. The report consists of an 18-page workshop summary, 18 PowerPoint presentations, and 8 poster presentations.

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