Seabed Geoacoustic Structure at the Meso-Scale

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LONG TERM GOALS

The long term science goals are to understand the nature of seabed variability at meso-scales O(10^1-10^3) m and determine how meso-scale structures impact acoustic propagation, diffuse reverberation, and clutter.

OBJECTIVES

The objectives are to develop new observational methods to quantify meso-scale seabed variability/ uncertainty and also develop modeling techniques to understand the impact of spatial variability on propagation and reverberation.

APPROACH

The observational approach is based on direct path measurements of seabed reflection and scattering. The key advantages of this approach are: 1) high resolution vertically, 0.1m and laterally: inner scale of ~10m and outer scale of 100 km; 2) it substantially reduces uncertainties from the space/time-varying oceanography and biology due to short path lengths; 3) it requires a low source level, 4) can be hosted on an Autonomous Undersea Vehicle (AUV), permitting observations of 3D meso-scale features, and making it an attractive eventuality as a survey tool. A cartoon of the system is shown in Figure 1.

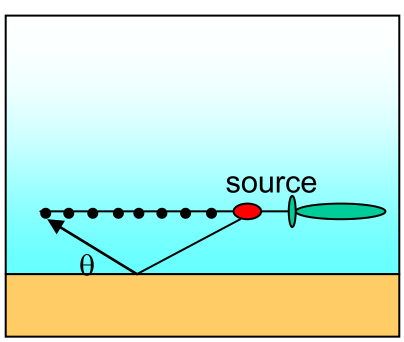

Figure 1 Cartoon of system for measurement of geoacoustic meso-scale variability

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Determining the impact of sediment meso-scale variability on propagation, reverberation and clutter will be addressed via modeling, both with simulated and measured meso-scale variability. The modeling builds on past work using energy flux methods (e.g., [1],[2]) along with PE and normal mode methods, in collaboration with Dale Ellis, (DRDC-A), Kevin LePage (NURC) and others.

Modeling studies employing the simulated meso-scale has the advantage of providing a deeper understanding of effects for a various canonical types of variability, accepting the disadvantage that since relatively little is known about the meso-scale, the simulation may or may not be representative of environments that actually exist. While there are some early insights into effects of meso-scale variability on propagation [2] in relatively simple environments, the more challenging problem of impact on diffuse reverberation and clutter needs to be addressed. The impact of meso-scale variability on clutter will be divided into two sub-classes, one where the meso-scale variability is so strong that it is essentially a discrete feature and produces clutter. In the other sub-class, the geoacoustic variability is weak, but may lead to focusing effects that produce clutter.

The measured meso-scale variability will also be used to predict the effects on propagation and reverberation. It will be important to explore both predictions with geometries/sonar parameters that were actually used in the long range propagation and reverberation measurements (as a crucial validation step) and also predictions with other geometries/sonar parameters that might reveal significant effects not possible to observe during the experiment.

WORK COMPLETED

The main FY11 effort was analysis of meso-scale variability from reflection measurements on the outer shelf of the Malta Plateau. We also began simulating meso-scale structures and their the effect on sonar clutter and explored the use of coherence of the reflected field (with Laurent Guillon) to quantify small to meso-scale sediment structures.

RESULTS

One of the major results in FY11 was analyzing meso-scale variability along a 14 km track on the Malta Plateau (see Figure 1). The track was selected along an ostensibly ‘benign’ section of the outer shelf where seismic data showed smooth slowly varying nearly flat sediment layers and nearly flat bathymetry. Thus, the intent was to examine the meso-scale in a region where variability should be modest.

The analysis revealed three classes of variability. The first class was expected and is due to slow horizontal variability of layer thicknesses: this variability could be directly tied to variability observed in seismic reflection data. The second class is due to rapid changes in layer properties and/or boundaries, occurring over scales of meters to hundreds of meters. The third class was observed as rapid variations of the angle/frequency dependent reflection coefficient within a single observation, and is suggestive of variability at scales of meter or less. Neither the second nor the third class could be tied to anything observable in the seismic reflection data. Though generally assumed to be negligible in acoustic modeling, the second and third classes are indicative of strong horizontal geoacoustic variability along a layer. The observations give early insight into possible effects of horizontal geoacoustic variability on long-range acoustic propagation and reverberation. The details are contained in Ref [3], here we provide just one of the results.

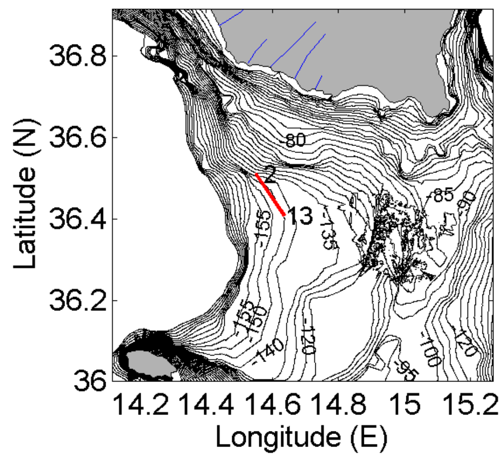

Figure 2. Location of track (red) for seabed reflection measurements. The islands of Sicily and Malta are to the north and south respectively. The track lies along portion of the shelf that is nearly flat, both from the from the point of the seismic reflection data (not shown) and the bathymetry.

The most surprising result in this 'benign' area, occurring along several sections of the track, was observations of very strong lateral variability. One example is shown in Figure 3 at about 3km from Site 13 (see Figure 2). Each of the 9 panels in Fig. 3a (left-hand group) shows the broadband reflection coefficient with an advance of the measurement system of about 3.6 meters, from upper left to lower right. The data were processed by using 1 ping and all 32 channels of the receive array for each panel. The data in pings 2760-2761 contain the 'correct' frequency-angle dependence of the reflection coefficient, where the fringe pattern is due to resonance effects within the multi-layered seabed. On the other pings, the abrupt shift in fringe patterns indicates that the angular dependence is co-mingled with range-dependence.

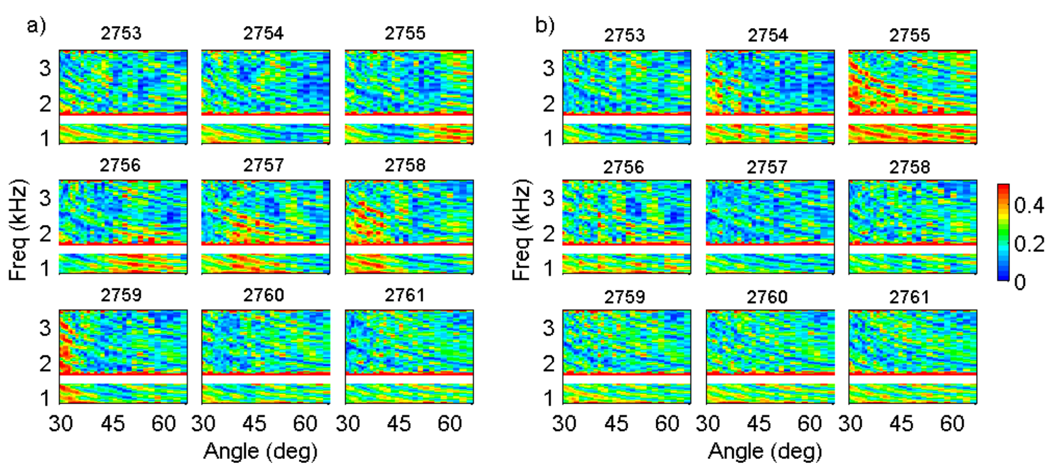

Figure 3 Reflection coefficient variability for 9 consecutive pings using a) all hydrophones from each ping and b) modified CDP that minimizes the spatial extent of the reflection coefficient by using hydrophones from multiple (5) pings for each reflection coefficient panel. Note that the high levels spread across 5 pings (2755-2759) in a) are largely confined to a single result mCDP 2755 in b).

The along-track spatial resolution can be improved by computing the reflection coefficient using a modified Common Depth Point approach (mCDP, see [3]) as shown in Fig 3b. Note that the high reflectivities are mostly confined to a single ping, mCDP ping 2755. The behavior of R_s with angle, frequency and position provides insight into both the spatial scale of the variability as well as the probable seabed feature causing the variability. Analyses (details in [3]) show that

1) the high reflectivity in ping 2755 (about a factor of 2 higher than the other pings) is not due to an irregular shaped object, e.g., a rock outcrop. Rather, it must result from a feature that is flat and of nearly uniform thickness over the measurement footprint. This can be deduced from the presence of the regular fringe or interference pattern.
2) The along-track extent of feature is about 5m and the cross-track extent must be greater than 7m.

This scale of feature could easily lead to sonar clutter and it was of interest to estimate the geoacoustic properties of the feature and its environs through inversion ([3]). The inversion estimates (in collaboration with Jan Dettmer, Un. Victoria) of sediment sound speed, density and attenuation (Figure 4) provide important insights into the possible effects of this meso-variability on propagation, reverberation, and clutter. The reflection and geoacoustic variability over this short track is striking. Note that the doubling of the reflection coefficient at mCDP 2755 over several meters appears to be due to a significant increase in density in the upper 4m (Figure 4). A geologic process potentially responsible for such variability is a small-scale (roughly 5 m wide) channel cut into the shelf possibly at low stand when the water depth would have been of order 10m. An unusually large episodic flooding event could have brought substantially coarser material into the channel and deposited fine-grained material on the channel banks and levees. Thus, the high density material at mCDP 2755 could be related to the channel fill and the mCDP 2753 and 2757 could represent the banks and levees. It was observed that the mCDP 2753 and 2757 reflectivities are measurably smaller than those tens of meters from mCDP 2755, which fits with the levee speculation.

In order to gain insight into how the variability would impact long-range propagation, the low angle plane wave reflection coefficient was calculated from the geoacoustic model (*Figure 4*, heavy solid lines). The dashed lines show the 95% confidence levels, computed based on combined uncertainties (including cross-correlations) of all parameters. Ignoring for the moment that this is a very short section of the entire track, theory [2] indicates several important things: 1) low (not high) reflectivity controls range-dependent propagation, thus mCDP 2753 and 2757 will have a disproportionately large effect on propagation, 2) range-dependent propagation is influenced by range-dependence of the reflection coefficient, thus notwithstanding the difference in geoacoustic properties for pings 2753 and 2757, since the low angle reflection coefficient is quite similar, the effect on propagation will be similar as well.

In order to gain insight into how the variability would impact long-range reverberation, it is useful to separately consider diffuse reverberation and clutter, where the former is defined as the smooth time decay of the reverberation and the latter as 'target-like' returns or possessing non-Rayleigh (heavy tailed) statistics. The diffuse reverberation in a range-dependent environment is sensitive to both the lossiest reflectivities (like propagation), as well as layer roughness and/or small-scale fluctuations in density. Clutter tends be controlled by high lateral variability at scales from $O(10^0\text{-}10^2)$, particularly in large-scale density fluctuations which generally controls backscatter. The rapid change in density evidenced by Figure 3 and Figure 4, strongly suggests that this kind of meso-scale variability would lead to clutter, i.e., observed as heavy tailed, non-Rayleigh reverberation.

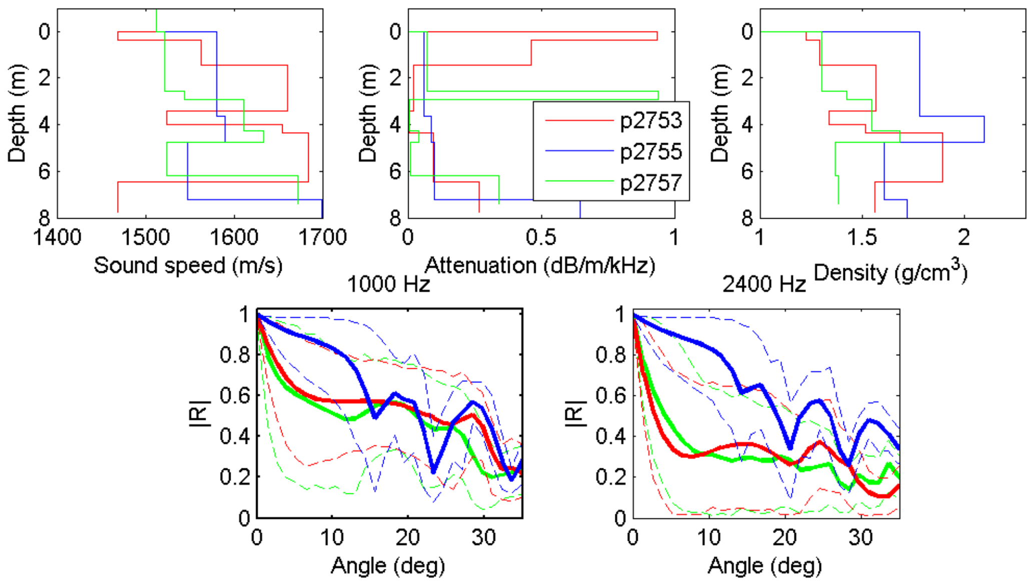

Figure 4 A comparison of the geoacoustic properties for three pings, mCDP 2753, 2755, 2757 in the upper 3 panels along with the predicted plane wave reflection coefficient at low angles (lower 2 panels). In the lower panel, the heavy solid lines represent the center of the distribution and the dashed the 95% confidence interval. The low angle plane wave reflection coefficients provide insight into long-range propagation as discussed in the text.

IMPACT/APPLICATIONS

This research has important implications for the development of next-generation Navy seafloor databases. Firstly, inasmuch as there is a recognized serious shortfall in the current Navy standard mid-frequency bottom database, HFBL, we postulate that this is in large measure because our community does not understand meso-scale geoacoustic variability (that is likely to play an important role at that frequency). Secondly, the measurement approach conceivably could be transitioned to an off-board sensor system that would significantly increase the quality/resolution of seabed surveys for NAVOCEANO, while decreasing the cost.

In addition to the need for reliable measurements/static databases, realistic time-series modeling needed for simulation and stimulation requires understanding and adequate modeling of the full range of scales: fine- to meso- to large-scale variability. It may be that meso-scale variability is one of the most crucial (but missing) scales for high-fidelity modeling. This is particularly true for clutter modeling and simulation which has been identified as a critical shortfall for surface ship and air simulation/trainers. Understanding the meso-scale variability will provide the basis for development of the underlying physics-based models.

RELATED PROJECTS

ONR Quantifying Predicting and Exploiting (QPE) Uncertainty: data/methods for quantifying geoacoustic variability and uncertainty developed in this project are being leveraged to QPE.

ONR Applied Reverberation and Modeling Board: would provide a platform for exploiting understanding of reverberation and clutter to the applied community, especially in the area of modeling and simulation.

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[3] Holland C.W., P.L. Nielsen, J. Dettmer, and S.E. Dosso, Resolving meso-scale seabed variability using reflection measurements from an autonomous underwater vehicle, J. Acoust. Soc. Am., in review.

PUBLICATIONS

Holland C.W., P.L. Nielsen, J. Dettmer, and S.E. Dosso, Resolving meso-scale seabed variability using reflection measurements from an autonomous underwater vehicle, J. Acoust. Soc. Am., [in review, refereed].

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