Seabed Geoacoustic Structure at the Meso-Scale

Charles W. Holland
The Pennsylvania State University
Applied Research Laboratory
P.O. Box 30
State College, PA 16804-0030
Phone: (814) 865-1724 Fax (814) 863-8783 email: holland-cw@psu.edu

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LONG TERM GOALS

The long term science goals are to understand the nature of the seabed at geoacoustic meso-scales $O(10^0–10^3)$ m and determine how these 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 approach includes both theoretical and measurement components. One measurement approach exploits the very high geoacoustic information content in direct path measurements of seabed reflection and scattering. Another measurement approach, based on long-range reverberation, has much less information content but is nonetheless a powerful way to explore scales inherent in the seabed. Both kinds of measurements were employed in the FY13 research.

WORK COMPLETED

The FY13 research focused on understanding fundamental acoustic properties of the sediments, especially the dispersion, i.e., intrinsic frequency dependence of the sound speed and attenuation. We developed

- a new method (Ref [1]) of estimating dispersion and separating its freqeuncy-dependent effects from frequency-dependent effects from layering. The method also has the virtue of determining the attenuation mechanism (which itself can be a function of frequency), that is, friction or viscous losses. (in collaboration with Jan Dettmer, U. Victoria)
- new measurements of 1000-3600 Hz attenuation in a muddy sediment fabric using long-range diffuse reverberation (Ref [2], in collaboration with Stan Dosso, U. Victoria)). The importance of this is that a) there is a glaring pacity of measurements in the 600 – 4000 Hz band b) that attenuation in muds has historically been very difficult to measure at all freqeuncies due to

measurement biases (see Ref [3]) and c) uncertainties in the measurements are almost never reported. Our measurements showed quite low uncertainties – average attenuation in a 10 m thick mud layer was 0.009± 0.003 dB/m/kHz.

In addition to these advances, the PI also collaborated with Gavin Steininger, Stan Dosso and Jan Dettmer to estimate roughness parameters from backscattering data (Refs [4] ,[5]). This represents the first time there has been an objective inverse method applied to seabed scattering data to provide not only the scattering parmaeters, but also the parameter uncertainties.

Also, the PI collaborated with Samuel Pinson and Laurent Guillon in developing methods for fast estimation of 2D sediment sound speed (vs depth and range) in range-dependent environments from an AUV and towed array (Ref [6]). Unlike more traditional inversion techniques this approach is computationally light and can be performed in real time on a laptop computer.

RESULTS

Here, we briefly summarize the research results for the dispersion measurements; for details see Ref [1]. Details of the other major advance, measuring attenuation in muddy layers using reverberation can be found in Ref [2].

A major challenge in measuring dispersion is the difficulty in separating intrinsic dispersion from other frequency-dependent effects including, presence of layers, gradients, shear effects, and volume heterogeneities. The main accomplishment was to show the ability to separate these effects and estimate the intrinsic dispersion, as validated with core measurements.

The fundamental observation is the magnitude of the reflection coefficient as a function of angle, frequency, and integration time. The advantage of the method is that *in-situ* (i.e., undisturbed) sediments can be measured with a high information content on layering and gradients over a wide range of frequencies, here 300 – 3000 Hz. Striation patterns ($\lambda/4$ resonances) in the data are the key to disentangling the layers and gradients from other frequency dependent effects. In order to interpret the reflection data the Buckingham viscous grain shearing (VGS) model [7] was employed. VGS was specifically chosen because it allows a smooth transition between two mechanisms that control the attenuation: fluid viscosity and friction. This general description of the physics permits identification of which mechanism(s) are present, via the frequency dependence of the reflection data.

The ability to recover intrinsic dispersion from layers and gradients was examined by a simulation, in which the true parameters are known and the sensitivities (and information content) of the data can be carefully examined. The test case included 4 layers, one with a strong gradient, over a halfspace. Noise was added for realism. The results showed that the intrinsic dispersion could be estimated quite accurately and with low uncertainties, showing that the information content of reflection data is sufficiently high to separate layering effects from dispersion.

The method was applied to measured reflection data with the same angles/frequencies and noise levels as the simulation. The measurements were conducted on the outer shelf of the Malta Plateau at 153 m water depth. Seismic reflection data (not shown) show a plane-layered sedimentary structure. The reflection coefficient was processed with an integration time corresponding to the upper 4 meters of sediment (see data (x) in Figure 1). The inversion model fits are also shown (in red); note that the forward model captures the frequency and angular dependence of the observations quite well. The model-data errors averaged over angle at various frequencies range from about 6e-3 to 4e-2 with a mean of 2e-2.

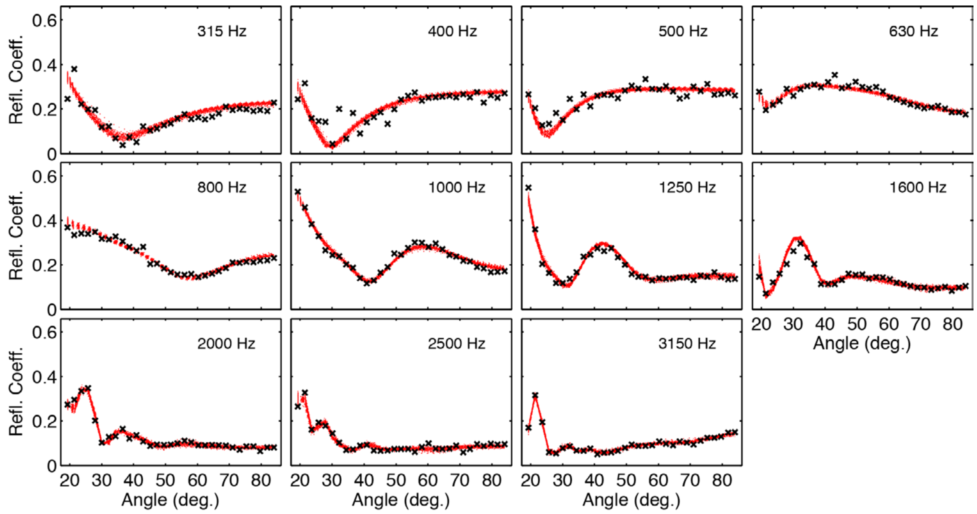

Figure 1 Measured reflection coefficient (x) along with the 95% highest probability distributions inversion fits (lines).

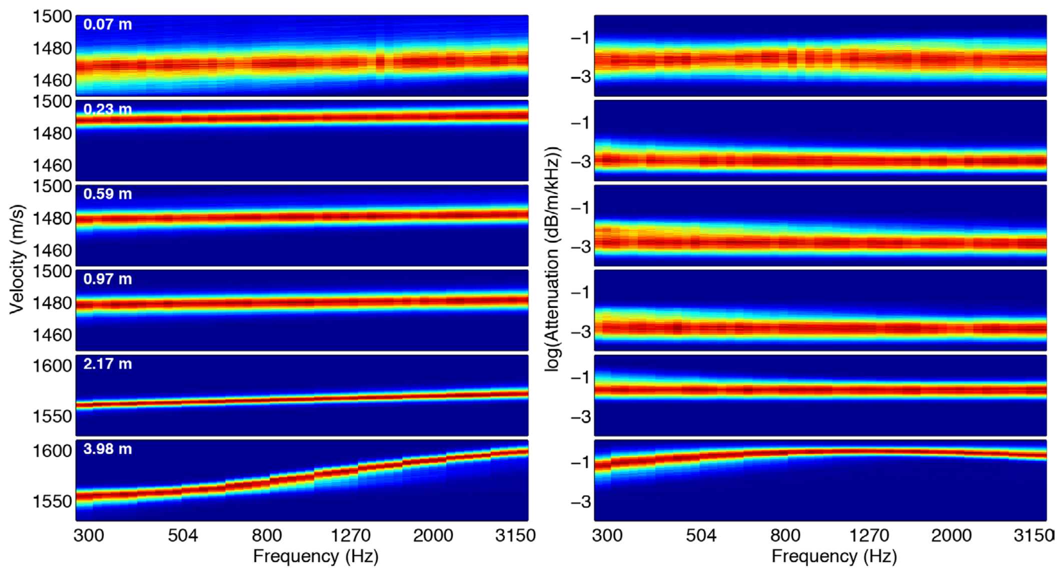

Figure 2 sediment dispersion curves at several depths below the seafloor. The red regions are approximately the 95% confidence interval for the solution.

The resulting marginal distributions of the dispersion curves are shown in Figure 2 which are a selection of depths from the solution space (which contains dispersion at all depths). The upper layers (upper panels) show sound speed nearly constant with frequency and attenuation approximately linear with frequency. The bottom halfspace, by contrast shows 45 m/s dispersion and an attenuation that rapidly and nearly linearly changes from $f^{1.8}$ to f^{1} between 300 and 1100 Hz, and then asymptotes to $\sim f^{1/2}$ at higher frequencies. The clear depth dependence of the dispersion shows that it is not only important to resolve layering because under or over-parameterizing the number of layers can lead to biases in the dispersion, but that dispersion can be a strong function of depth, varying layer by layer.

In Ref [1], the dispersion measurements are carefully compared with core data. The dispersion estimates compare favorably with the core in the upper part of the core. For example, Fig 3a shows a comparison of the estimated dispersion from the reflection data (blue solid line) which is extrapolated (blue dashed line) using the VGS parameters obtained from the 315-3150 Hz measurements up to the core measurement frequency, 200 kHz. The extrapolated value agrees very closely with the core measurements. However, below 2 m depth in the core (where there were large numbers of shells and shell fragments) there was poor correlation between the estimated velocity and the core measurement. Given the shell dimensions and numbers, it is clear that the 200 kHz core measurements were biased (low) due to multiple scattering. In Fig 4b, a simple multiple scattering model (gray lines) extrapolated from the dispersion estimates (solid blue) shows the negative dispersion predicted from the shells.

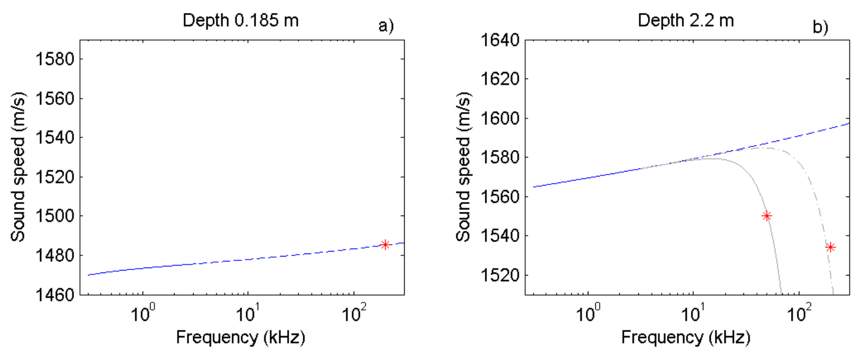

Figure 3. dispersion from inversion of reflection data (solid) compared with core data (*) at depths where a) there were no shells, 0.185 mbsf and b) shells were present 2.2 mbsf. The dashed lines are VGS predicted from the MAP model derived from the reflection data. The core measurements in the shelly layer have been interpreted with a multiple scattering model corresponding to particle sizes of 2 mm (dashed gray) and 6 mm (solid grey).

IMPACT/APPLICATIONS

The ability to separate frequency-dependent effects of layering and gradients from intrinsic attenuation opens a promising avenue for measurements in the ONR SCAE15 field experiment whose main science objective is to measure dispersion. There is good evidence from our results that cohesive sediments (clays and muds) exhibit attenuation that goes as frequency to the first power. This implies that the attenuation mechanism is related to frictional forces as opposed to viscous losses. This could also be valuable to those in the community interested in developing phenomenological models of wave propagation through clay fabrics. Measurements made this year in muds (see Ref [2]) show remarkably small values of attenuation, 0.009 +- 0.003 dB/m/kHz. This likewise should be useful both for the theoretical developments as well as in experiment design for the mud sites contemplated in SCAE15.

RELATED PROJECTS

ONR shallow water field experiments: the advances here will motivate experiment design to distentangle effects of sediment dispersion from other frequency dependent effects.

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