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(10^0–10^3) 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 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.

Theoretical studies employing simulated meso-scale variabilityhas the advantage of providing a deeper understanding of its effects, 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 [1] 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.

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WORK COMPLETED

There were two significant FY12 discoveries: 1) that clutter that can be generated by non-discrete sediment structures (Ref [2]) and 2) discovery of a persistent scale that controls reverberation in ostensibly geologically diverse shallow water regions (Ref [3]).

RESULTS

Both FY12 discoveries are viewed as significant advances in understanding of seabed effects on reverberation and clutter and will be briefly reviewed.

A. Clutter from non-discrete seabed structures, Ref [2]. One of the most challenging issues in use of active sonar is the problem of clutter: spiky, target-like returns that can overwhelm a detection system. In bottom-limited areas, one of the primary sources of clutter is from the seabed. In some areas, false alarm rates are so high that active systems may be rendered nearly useless. It is important to understand the mechanisms that lead to clutter, not only for designing more robust signal processing algorithms, but also for realistic modeling required for training and simulation.

An important class of clutter mechanism is discrete objects that lie on the bottom, e.g., wrecks, pipelines, rock outcrops, and mud volcanoes. It has been shown that buried discrete objects may also lead to clutter (e.g., buried mud volcanoes or step changes in impedance). It is intuitive that scattered returns should come from discrete features that have a spatial scale of order of the target of interest. However, there are experiments, even those with state-of-the-art geophysical surveying equipment, in which observed clutter could not be correlated with any discrete objects in the: water column, seabed interface, or sub-bottom [4]. One possible explanation is from focusing due to curvature of the seabed [5], another possibility is an angular steepening of the incident field on the seabed due to oceanographic effects [6].

The main result shown in [2] is to reveal a new class of mechanisms that can lead to clutter: slowly and continuously varying sediment layers. It is not at all intuitive that something in the ocean environment that is slowly varying should lead to sharp or spiky returns. However, the results [2] not only demonstrate that such clutter can exist, but explore the conditions under which it is expected to be important for low to mid-frequency active systems (100-10,000 Hz).

Consider an isovelocity 100 m depth waveguide with a fine-grained sediment (silty-clay) layer over a sand halfspace with range independent properties (*Figure 1*b). The reverberation intensity at 2 kHz decays smoothly with time (*Figure 1*a). Now consider the same case with a slowly varying sediment thickness (*Figure 1*d) and all other properties are range-independent. Note that from the point of view of a surficial sediment map (or grab samples or short sediment probe measurements), the seabed in *Figure 1*d would appear to be range independent. Note also that the slope associated with the layer thickness change is very small, less than 0.1 degree (the large vertical exaggeration in the figure makes the slope appear much larger than it is. The reverberation from this ostensibly benign environment at 2 kHz center frequency and 100 Hz bandwidth is shown in *Figure 1*c. The salient feature is the strong reverberation peaks that occur for each scattering mechanism: the sediment basement, the sediment volume and the water-sediment interface.

In its essence, the clutter-like features in the reverberation are due to the presence of nulls in the reflection coefficient. These nulls result in a high incident field in the sediment volume and at the rough basement boundary at specific values of *kd*, where *k* is the wavenumber and *d* the sediment thickness. For the parameters of this environment the nulls occur at $d^{(n)}$ =[0.47, 2.07 3.67 5.27 6.87] m, corresponding to ranges along the linear wedge of [9.9 8.9 7.8 6.8 5.7] km. Theory was developed to explain the dependence of the clutter peak height and width on the environmental parameters. The theory also showed that these clutter events can also occur with a constant layer thickness but with slowly varying sound speed/density. The clutter events can also occur even with a range-independent seabed but slowly varying bottom water sound speed (Ref [2]).

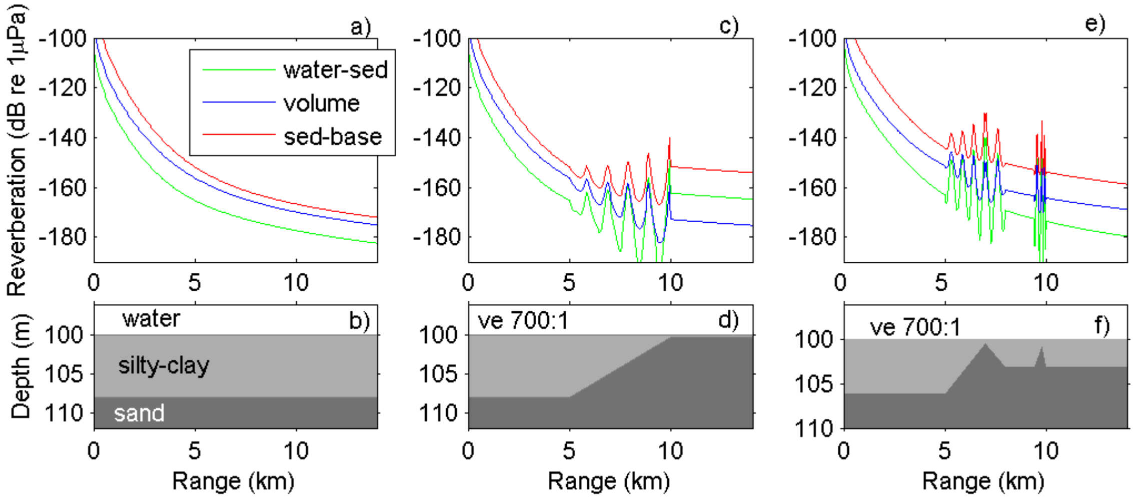

Figure 1. Reverberation at 2 kHz from a 10 ms continuous wave pulse from (a) range-independent seabed and (c and e) slowly varying range-dependent seabed. The environments given in (b, d and f) have a large vertical exaggeration (ve) of 700:1, i.e., the slope in (d) is less than 0.1 degrees and in (f) less than 1 degree. The salient feature is the large peaks in the reverberation in (c) and (e).

B. Evidence for a common scale O(0.1) m that controls seabed scattering and reverberation in shallow water, Ref [3]. It is understood that seabed scattering can arise from interface roughness, including sub-bottom interfaces, and/or from heterogeneities within the sediment volume. An important question has been: Which mechanism dominates and at what frequencies and in what geophysical regimes.

Analysis of the spectral content of long-range reverberation yielded two observations. First, there is a remarkably similar scale, O(0.1)m, between 3 diverse continental shelf regions. This is surprising given general understanding of the complexity and diversity of geologic processes. Second, there is strong evidence that the scale is associated with heterogeneities within the sediment. Thus sediment volume scattering, not interface scattering, controls long-range reverberation from a few hundred Hertz to several kiloHertz. This is also unexpected given that at long-ranges the vertical grazing angles are less than the critical angle, and hence the penetration of the acoustic field into the sub-bottom is expected to be modest. The consistency of the scale, O(0.1)m, suggests an underlying feature or mechanism that is consistent across many ostensibly diverse geological settings.

Seabed scattering from random inhomogeneities can be described by a von Karman spectrum. One of the parameters, spectral cut-off defines an outer scale of the inhomogeneities and it turns out can be easily estimated from long-range reverberation from the 'knee' in the spectrum. An example at one location is shown in *Figure 2*. Note the knee in the reverberation data (gray) at about 1 kHz. Modeling (green line) shows that this behavior is from a spectral cutoff of 0.2 m and that the scale must be related to sediment volume scattering and not interface scattering [3]. Reverberation spectra at two other diverse locations show a remarkably similar scale. While this newly discovered persistent scale falls outside of the defined mesoscale above, it nevertheless is of significant interest for low to mid-frequency active sonar as well as sediment acoustics.

Five hypotheses were explored that could explain the scale and its persistence: lateral heterogeneity from geologic processes via layer deposition and erosion, sediment gas, gas bubbles in the water column, pebbles, and shells. While the mechanism cannot be isolated at this time, the most likely mechanism appears to be shells from the standpoint of expected spatial persistence and from biologic factors which limit their scale.

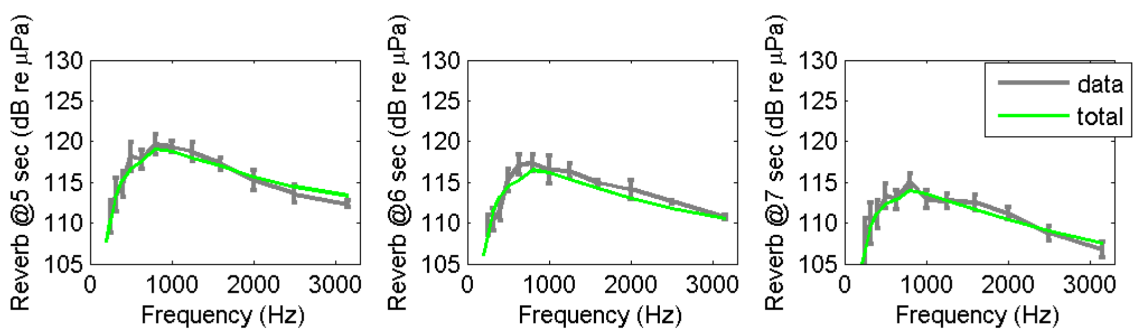

Figure 2. Reverberation data (gray) from the northern Tyrrhenian Sea. Note the 'knee' in the reverberation curve around 1 kHz. The model (green) captures the knee quite well with a volume scattering spectral cut-off of 0.2 m.

IMPACT/APPLICATIONS

The discovery that clutter can come from very slowly varying seabed layers or properties is important because a) it motivates experimental programs to examine this as a potential mechanism, and b) it affects (i.e., broadens) the development of clutter databases. The next major step will be to verify experimentally that this effect does occur on the mid to outer shelf.

The newly discovered persistent scale in the sediment volume, order 0.1 m, has several applications including active sonar systems and sediment acoustics. Regarding the former, to date the vast body of work on active sonar modeling has generally assumed interface scattering. Results [3] show that low to mid-frequency sonar systems may often be working against reverberation generated from sediment volume heterogeneities with a spectral cut-off of order 0.1 m. This may be useful for design of processing algorithms or new and emerging systems. Regarding sediment acoustics, the persistence of scattering from this scale strongly suggests that our current sediment models (fluid, solid, or poro-viscoelastic) are missing an important component that may have important implications particularly for understanding the frequency dependence of attenuation.

RELATED PROJECTS

ONR SW2013 and SW2015 experiment: the discoveries here motivate experiment design to determine if a) clutter from slowly varying layers is a mechanism at the proposed experimental sites and b) volume heterogeneites at a scale order 0.1 m control the diffuse reverberation.

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

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