Geoacoustic Physical Modeling: Volume-Roughness Interactions

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LONG-TERM GOALS

The long-term scientific objective of this research is to develop a geoacoustic model of the seafloor for better understanding the physics of interaction between sound and marine sediments. The emphasis is on phenomena encountered in the interaction of high-frequency acoustic signals with littoral ocean bottoms.

OBJECTIVES

The specific objective of this research is to investigate the physics of volume-roughness interactions in sea bed scattering using both theoretical modeling and controlled experiments in NRL tank facilities.

APPROACH

This project is a part of collaboration between APL and NRL, which involves both theoretical study of volume-roughness interactions and water tank measurements of scattering from various fabricated physical models, such as plates with rough surface and various inclusions in their volume, to imitate scattering from the littoral ocean bottom (e.g., rough sandy sediments with inclusions of shells, rocks and gas bubbles).

The results of this study can be relevant to explaining interesting effects which should be observed in acoustic scattering from rough heterogeneous natural media, such as marine sediments. These effects are caused by volume-roughness interactions and should be very pronounced at near- and sub-critical grazing angles. For example, the very first theoretical considerations by [Ivakin and Lysanov, 1981] predicted the dramatic enhancement of volume scattering in the sediment at these angles because of enhanced penetration due to interface roughness. It is important to emphasize here that the increase of a buried target scattering strength due to this (related to the bottom roughness) sediment penetration enhancement (which was a major subject for study in recent shallow water experiments, e.g., SAX99) is necessarily accompanied by an enhancement of the sediment volume component of bottom reverberation due to the volume-roughness interactions.

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14. ABSTRACT
The long-term scientific objective of this research is to develop a geoacoustic model of the seafloor for better understanding the physics of interaction between sound and marine sediments. The emphasis is on phenomena encountered in the interaction of high-frequency acoustic signals with littoral ocean bottoms.

15. SUBJECT TERMS

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The laboratory experiments to test such effects were planned to take place at the NRL Shallow Water Acoustic Laboratory in FY08 using experimental techniques developed recently and described by [Soukup et al, 2005, 2006]. It was assumed to use various plates made of wax with glass bead inclusions as physical models of the sediments, and to study scattering from such models in the 50-300 kHz frequency range. In order to work with a material with a lower critical grazing angle, NRL tested various materials that would have lower speeds than wax, yet remain capable of being milled into precise rough surfaces. After testing wax models with glass powder inclusions, it was decided to try a different material (a specific type of polyurethane). This material was suitable for creating models with heterogeneities while having a speed of less than 1700 m/s. In the NRL base-funded project, the Materials Science Division was tasked to produce models for which randomly distributed inclusions were contained within the rough surface of a model. The technical problems involved in creating a random distribution of glass bead inclusions have been too great (an attempt by a French facility to have a private company perform a similar task for a silicone model was also unsuccessful). It is unlikely that the model for direct treatment of volume/roughness interactions will be able to be fabricated (although another attempt to make a flat model with random inclusions will take place in FY09). Therefore, we are currently deciding on appropriate work that could be done with existing models, the most relevant to the high-frequency volume scattering model being an experiment (scheduled to December) with polyurethane model with layered inclusions.

Due to these issues, the focus of this project currently is shifted towards theoretical study of these effects and its direct application to analysis of the SAX99 backscattering data obtained by [Williams et al, 2002] in the same frequency range for a well characterized sand sediment.

WORK COMPLETED AND RESULTS

In [Ivakin, 2005], a hypothesis was proposed that volume-roughness interactions are responsible for high level of the SAX99 bottom reverberation observed at frequencies above 150 kHz at subcritical grazing angles (below 30 degrees). This effect is illustrated in Fig.1. In this figure, various symbols show frequency dependence of bottom backscattering strength at two fixed grazing angles, 35 and 20 degrees, representing angles above (left) and below (right) the critical grazing angle, which is about 30 degrees for sandy sediments at the SAX99 site. Dash-dot curves show roughness scattering predictions in accordance to measured at SAX99 sea bed roughness spectra. The comparison shows, within an allowed uncertainty, that the roughness scattering model fits the data reasonably well at frequencies below 100 kHz. However, at higher frequencies, predicted roughness scattering is substantially lower than the observed level of scattering because the level of roughness spatial spectrum was found to be too low at the corresponding spatial frequencies at SAX99 site due to a break in the bi-power law [Williams et al, 2002]. Analysis supports the existence of such an important break by showing its relationship to the angle of repose, a fundamental feature of granular sediments (such as sands)[Ivakin, 2005]. Therefore, analysis of roughness scattering model/data comparisons has shown that other mechanisms of scattering must be considered and other approaches are required for understanding SAX99 data.

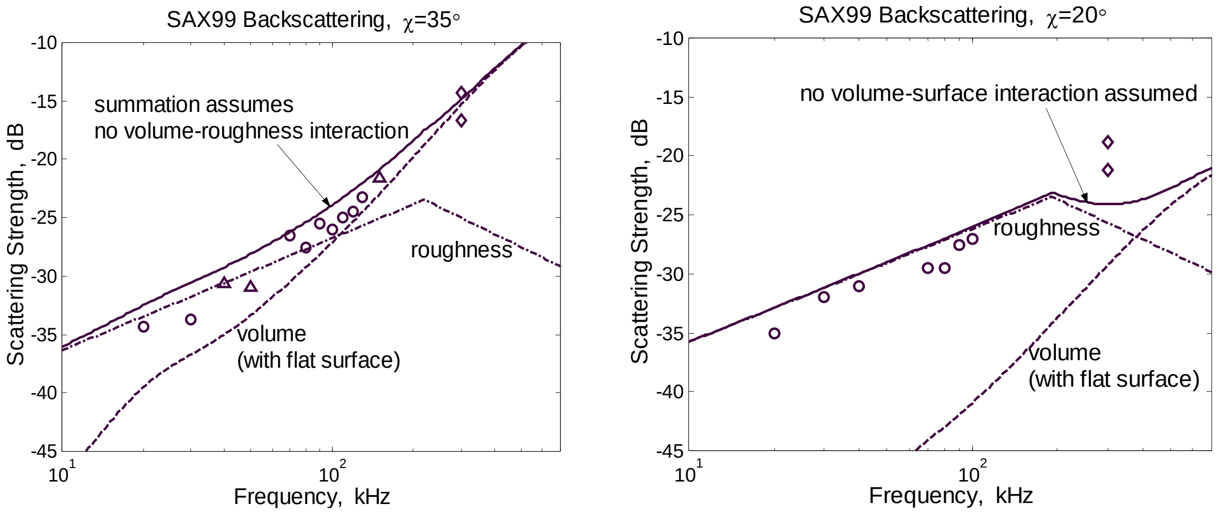

Figure 1: Model-data comparison for frequency dependence of SAX99 seabed backscattering strength at a fixed grazing angle above (left) and below (right) critical. The model assumes a simple summation of the roughness and volume scattering components (no volume-roughness interaction).

In previous research [Ivakin, 2005], the discrete scattering mechanism was incorporated into analysis of SAX99 scattering data. An arbitrary stratification of discrete inclusions was considered, which allows depth-dependent grain size distribution exactly corresponding to that measured at the SAX99 site. The results for the frequency dependence of bottom backscattering strength are shown in Figure 1 by the dashed line. Model/data comparison shows that the prediction of volume scattering using the measured size distribution is a few dB lower than the observed bottom scattering at SAX99 at frequencies below about 100 kHz. Nevertheless, a simple summation of the two mechanisms, roughness and discrete volume scatterers, provides a good model/data comparison for backscattering for all frequencies used in SAX99 at grazing angles above critical. This result is illustrated in Figure 1 (left).

However, there is a serious problem in understanding and modeling backscattering for SAX99 at high frequencies (about 200 kHz and higher) at subcritical grazing angles. This is demonstrated in Figure 1 (right). In analogy with the case of grazing angles above critical, a simple summation of volume and roughness scattering was applied assuming no interaction between these two mechanisms. This means that roughness scattering is being calculated for homogeneous sediment (with no inclusions) and discrete scattering is being considered assuming a flat sediment surface (no roughness). This simplified approach, used successfully at higher grazing angles, as demonstrated in Figure 1 (left), fails in attempts to explain high frequency data at sub-critical grazing angles, see Figure 1 (right).

The discrepancy can be due to ignoring volume-roughness interaction. In the case of a flat water-sediment interface, at grazing angles below critical, volume scattering is significantly reduced because of the small depth of sound penetration into the sediment. In the case of a randomly rough interface, there are always facets with local grazing angles above critical, which cause an enhancement of sound penetration and consequent enhancement of volume scattering in the sediment. The effect can be very significant considering the fact that the slope of roughness at sub-cm scales at SAX99 site is large and can be close to both angle of repose and critical angle (about 30 degrees).

Therefore, the results of this analysis show, in particular, that the contribution of gravel and shell inclusions and coarse sand fraction in total scattering at the SAX99 site can be dominating (over roughness) at high frequencies (about 100 kHz and higher) and grazing angles above critical (about 30 degrees) while roughness is likely a dominating mechanism of bottom scattering at lower frequencies and grazing angles below critical. A simple summation of the two mechanisms, roughness and discrete volume scatterers, provides a good model/data comparison for backscattering for all frequencies used in SAX99 at grazing angles above critical. A problem remains at subcritical grazing angles for high frequencies (about 200 kHz and higher) where there is a significant model/data discrepancy which can be due to ignoring volume-roughness interaction. The effects of such interactions can be very significant and require further theoretical considerations.

IMPACT/APPLICATIONS

The results on scattering from sediment models obtained in this research will provide a better understanding of bottom acoustic interaction at high frequencies. In particular, it is practically important to understand that the increase of the buried target scattering due to the bottom roughness is accompanied by an enhancement of sediment volume reverberation due to the volume-roughness interactions. The results of this research can be also used in algorithms for remote geoacoustic characterization of marine sediments (ONR, Code 321CG), as well as in other practical applications related with bottom target scattering and reverberation.

RELATED PROJECTS

This research is closely related to projects involving the study of acoustic interactions with heterogeneous ocean bottoms. NRL, APL/UW, CNRS/MRS and NURC will collaborate under an approved JRP for FY07-09 with a focus on tank experiments with physical models for buried objects and volume scatterers. This JRP is not a funded project, but rather an agreement for international collaboration that is included in the NURC Program of work, involving funded projects from these various organizations. The time frames of the JRP and this project are intended to correspond with the NRL base project by Soukup "Acoustic Interactions with Heterogeneous Media".

This research is also related to Ivakin's FY06-FY08 project "High frequency scattering from water saturated sandy sediments: Laboratory study" sponsored by ONR Ocean Acoustics and conducted in collaboration with Dr. Sessarego of CNRS/Marseille, France. That project also involves a laboratory study approach, which includes, however, experiments with natural sand sediments.

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