Remote Sensing Technique for Geoacoustic Characterization of Heterogeneous Marine Sediments

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LONG-TERM GOALS

The long term goal of this research is to develop an improved remote acoustic sensing technique for quantification of seafloor geoacoustical properties based on advances in theoretical and experimental studies of scattering in heterogeneous media.

OBJECTIVES

The scientific objective of this research is to evaluate various inversion algorithms and to assess conditions of their applicability for several specific types of heterogeneous rough sea beds. Another goal is to provide recommendations, first, on the choice of optimal parameters for acoustic measurements and, secondly, on accompanying environmental measurements of sediment heterogeneity. Also, it is proposed to start development of the sediment particulate size distribution data base for coastal environments.

APPROACH

Recently, a model of acoustic scattering from discrete inclusions in marine sediments was developed under sponsorship of ONR Ocean Acoustics Program [1-3]. The model has been demonstrated as a good descriptor of seabed backscattering measured at SAX99 experiment over a wide frequency range (30 kHz to 300 kHz). Importantly, the model is based solely on environmental measurements of seabed parameters. The critical sediment characteristic in this model is the size distribution for the coarse fractions of the sediment particles and inclusions. An advantage of this model is that it is quite simple and based on a small number of understandable and measurable parameters.

In this research, the “inclusion scattering” model [1] is used as a basis for development of practical inversion algorithms. These algorithms will be tested using acoustic and environmental data obtained in recent ONR sponsored experiments. Particularly, the algorithms are planed to be used for analysis of sea bed scattering data obtained at the SAX04 experiment conducted recently near Ft. Walton Beach, Florida, close to the location of SAX99. Both experiments were accompanied by extensive environmental measurements [4-7]. This will give an opportunity to test both prediction and inversion capabilities of scattering models and to validate the algorithms for remote sensing developed in this project.

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14. ABSTRACT
The scientific objective of this research is to evaluate various inversion algorithms and to assess conditions of their applicability for several specific types of heterogeneous rough sea beds. Another goal is to provide recommendations, first, on the choice of optimal parameters for acoustic measurements and, secondly, on accompanying environmental measurements of sediment heterogeneity. Also, it is proposed to start development of the sediment particulate size distribution data base for coastal environments.

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The discrete scattering model used in this research, in spite of its simplicity, is more general than a traditional and well developed technique used for the case of suspended in water fine particulate [A. Hay, J. Sheng and others]. In particular, our model takes into account water-sediment interface and considers larger discrete scatterers, such as coarse sand particles, gravel, rocks, shell hash, shelled animals etc, as inclusions embedded in a fluid sediment half-space with effective parameters, density, sound speed and attenuation, essentially different from those in water. In addition, a modified version of this model takes into account stratification of the inclusions [8].

One of the specific goals of this research is, using this model, to evaluate possibilities for an inversion of the sediment particle size distribution, or at least its coarse fractions, from multi-frequency acoustic backscatter. In particular, SAX99/SAX04 acoustic and environmental data will be used as follows. Measurements of the frequency-angular dependences of the bottom backscattering strength will provide inputs for the inversion algorithms. Environmental measurements conducted concurrently with and at the same location as acoustic experiments will serve as the ground truth and also will provide certain frames for possible variations of the inversion output parameters to provide a consistent estimation of the sediment properties.

WORK COMPLETED

At the beginning, a simplified version of the discrete scattering model was used where the inclusions are distributed in the sediment volume uniformly. Shell fragments and the coarse fraction of sand in the sediment volume are considered using the “inclusion scattering” model presented in [1]. Then, using this model, an inversion of the sediment particle size distribution was carried out from the SAX99 multi-frequency acoustic backscatter data. The result was compared with the sediment grain size distribution measured independently at the SAX99 site.

Next, the model of scattering was modified to take into account that the sediment grain-size distribution can be different at different depths [8]. For example, SAX99 environmental data shows that the size distribution for shell fraction is depth-dependent (stratified). Effects of this stratification on the frequency-angular dependence of the bottom backscattering strength was tested and possibilities of the inversion for the various parameters of the depth distribution of scatterers were evaluated.

RESULTS

Several kinds of scattering data inversions have been studied. The first one is based on the above-mentioned simplified model of scattering [1]. An example of model/data comparison and inversion for size distribution using this model is presented in Figures 1,2. In Figure 1, the volume size distribution for the SAX99 sediment at different depths is shown as a function of the equivalent radius of the particles (radius of the sphere with the same volume). The solid curve is a depth-independent multi-power law function which is the best fit to measured size distribution. The dashed curve is the size distribution inverted from acoustic scattering data, i.e., the multi-power law function which provides the best fit to measured backscattering data (shown in Figure 2). It is seen that the result of an inversion algorithm here is quite reasonable.

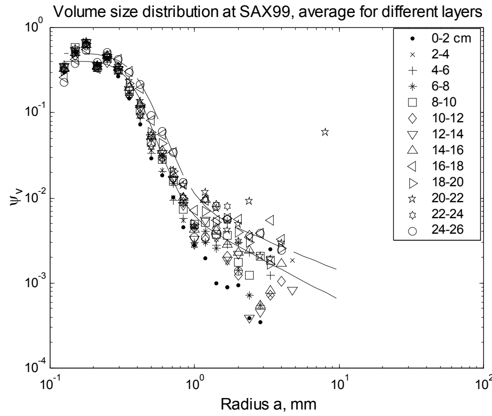

Figure 1. ***Volume size distribution for the SAX99 sediment at different depths (in-situ data). The solid line shows the best multi-power law fit to the in-situ data. The dashed line shows the result of inversion of the SAX99 acoustic scattering data.***

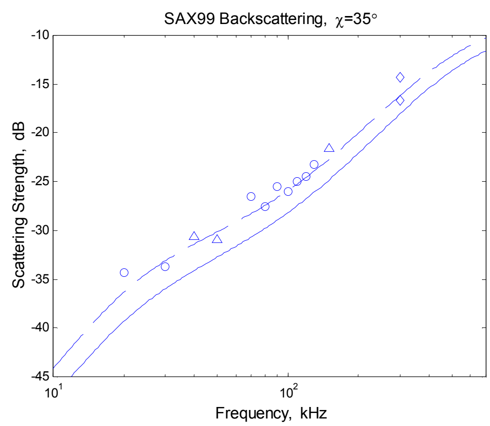

Figure 2. ***Frequency dependence of the bottom backscattering strength at SAX99. The grazing angle is 35 degrees. The solid line shows the scattering prediction using the best fit to the in-situ size distribution data (solid line in Fig.1). The dashed line shows the best fit of the discrete scattering model to the SAX99 data. The inversion using this model gives a slightly shifted size distribution correspondent to the dashed line in Fig. 1.***

Second kind of the bottom scattering data inversions is based on a modified version of the discrete scattering model [8] which considers possibility of stratification of sediment inclusions. For example, SAX99 environmental data shows that the size distribution for shell fraction is depth-dependent. Particularly, concentration of the coarse fractions (e.g., shell hash) is lower near the surface at 0-2 cm depth (see Figure 1). Acoustic effect of this fact was analyzed and illustrated in the following example. One can assume possibility of a finer stratification of the coarse fractions within the very top sediment layer (not seen in presented SAX99 data because of the 2 cm resolution). In this case, a simple although reasonable approximation for stratification of coarse inclusions in this top 2 cm layer would be separating this layer onto the two ones with a thiner layer near the water-sediment interface not having inclusions. The thickness of such homogeneous layer can be just a few mm, however the model analysis shows that even such a thin transition layer can provide a strong effect at sufficiently high frequencies where attenuation becomes substantial.

Figure 3 illustrates this “transition layer effect” [8]. In particular, it explains a remarkable roll-off at frequencies above 1000 kHz for bottom backscatter which was observed at the SAX99 site but has not been explained adequately [9]. The effect is very sensitive with respect to thickness and geoacoustic properties of the transition layer. Our analysis shows that the best fit of the model prediction and SAX99 data can be obtained for the thickness of the transition layer 3.5mm [8]. This value is very close to results obtained by Tang et al using the sediment conductivity measurements [10] and independently estimating the thickness of the sediment transition layer at the SAX99 as approximately 4 mm.

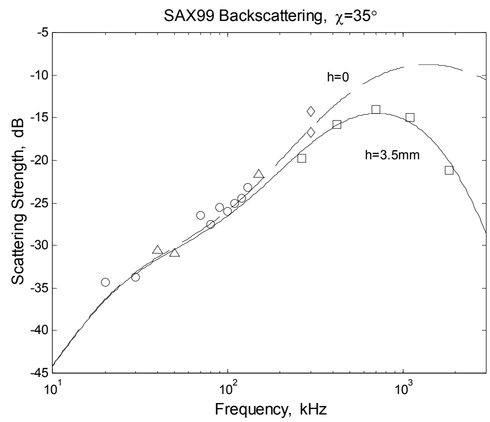

Figure 3. ***Effect of a thin (3.5 mm) top homogeneous (transition) layer at high frequencies. The frequency dependence of the bottom backscattering strength at SAX99 shows a remarkable roll-off above 1000 kHz. The solid and dashed lines show results for a model of discrete scattering respectively with and without the transition layer.***

This result is likely one of the main accomplishments of this research by now considering importance of the sediment transition layer. Properties of the transition layer are defined by complex physical, chemical and biological processes, hydrodynamics, sediment transport, bioturbations, pollution, etc. The above-mentioned example demonstrates a possibility that important information about these processes can be obtained using remote acoustic sensing. Note also, that it is very likely that the transition layer properties (e.g., the thickness) varies from site to site resulting in substantial spatial variability in high frequency acoustic scattering as well.

To consider possible effects of bottom roughness, the frequency-angular dependencies of the seabed scattering strength were calculated for rough but homogeneous seabed with bottom roughness parameters measured at SAX99. The results were compared with the described above discrete scattering model considering flat bottom using sediment parameters measured at SAX99 [8]. The comparison shows, in particular, that contribution of gravel, shell inclusions and coarse sand fraction in total scattering can be comparable with or dominating over roughness at frequencies higher than 50 kHz for near- and above- critical grazing angles. This means that, at these frequencies and angles, the algorithms for inversion of the sediment inclusions size distribution can use measurements of the total scattered field.

Another quite important conclusion has been made from this comparison and is related to a substantial decrease of the roughness scattering at high frequencies (at about 200 kHz and higher). This effect results from a remarkable break in roughness power law spectrum corresponding to a horizontal scale about 1 cm. Recent analysis [2] supports existence of such an important break by showing its relationship to the angle of repose, a fundamental feature of granular sediments (such as sands). Therefore, analysis of bottom roughness scattering can provide important information about processes related to sediment particulate transport and repose.

IMPACT/APPLICATIONS

This research will contribute to development of improved remote acoustic sensing technique for quantification of seafloor geoacoustical properties.

TRANSITIONS

The results of this work are being adapted in practical analysis of seabed scattering for geoacoustic inversions. For example, the inversion algorithms developed in this research are proposed for using in SAX04 data analysis (ONR, Code 321OA). Recommendations elaborated in this research, first, on the choice of optimal parameters for remote acoustic measurements and, secondly, on accompanying environmental measurements of sediment heterogeneity, can be used in planning of future experiments. Also, proposed development of the sediment particulate size distribution data base can provide a better description of coastal environments.

RELATED PROJECTS

This project is closely connected to SAX04 and Ripple DRI programs. This work was conducted in collaboration with investigators at the Applied Physics Laboratory, University of Washington (Drs. D. Jackson, K. Williams, D. Tang, E. Thorsos and others) and NRL (Drs. M. Richardson and K. Briggs). Also, collaboration with investigators at UNH is expected (Drs. L. Mayer, C. de Moustier and others).

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