Bottom Volume Scattering: Modeling and Data Analysis

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Abstract: Based on perturbation theory and the Born approximation, a volume scattering model is developed, which is capable of simulating the backscattered field and time series due to 3-D volumetric bottom inhomogeneities. The model predictions compare favorably to experimental data available between 250 and 650 Hz.

INTRODUCTION

As part of the Acoustic Reverberation Special Research Program (ARSRP), low-frequency bottom scattering from a deep ocean sediment pond was measured using an omnidirectional source and a vertical line receiving array deployed near the bottom. Sediment volume heterogeneities in two irregular layers beneath the water/sediment interface were found to be the major contributors to the measured scattered fields [1]. In this work, efforts have been made to model backscattering from 3-D sediment volume heterogeneities and to compare the results with the ARSRP backscattering data.

VOLUME SCATTERING MODEL

Sound speed and density fluctuations are generally considered major contributors to sediment volume scattering. The fluctuations in the bottom are usually small due to the nature of the sedimentation process. Therefore, the method of small perturbation is suitable and widely used in volume scattering modeling [2]. Together with the Born approximation, the scattered field can be derived as [3]:

\[ P_s(R_F) = \int \epsilon(r')[(2 + \beta)k_0^2(\delta c)P_0(R_F, r')G(R_F, r') - \beta(\nabla P_0(r') \cdot \nabla G(R_F, r'))]dr', \]

where \( R_F \) stands for the receiver position, \( r' \) stands for the scatterer position, \( \delta c \) the vertical dimension, \( G \) represents the Green's function, \( P_0 \) represents the mean field, \( k_0 \) the background wavenumber, and \( \epsilon(r) \equiv \frac{\delta c}{c_0} \), and \( \delta \rho \equiv \beta \epsilon(r) \) describe the sound speed and density fluctuations, with \( \beta \) a constant.

The scattered intensity can be obtained directly from the above equation and scattering time series can be simulated through Fourier synthesis. In this model, the Green's function is obtained through an exact numerical method (OASES). Therefore the model can handle any layered sediment environments with scatterers distributed within any of the layers. Sound speed and density fluctuations are described statistically by their power spectral density. Meanwhile, taking advantage of the experimental geometry, realizations of azimuthally-summed 3-D random inhomogeneities in the sediment can be generated effectively using the spectral method [3]. As a result, the model is capable of simulating scattered fields due to 3-D volume inhomogeneities.

MODEL/DATA COMPARISONS

The use of a vertical line receiving array enabled the application of a beamforming technique to estimate the backscattering strength in different directions. Details of the ARSRP experimental scenario and data processing were given in [1]. In the present work, model and data comparisons are carried out in terms of backscattering strength versus grazing angle for a selected set of frequencies over the signal spectrum. The parameters for the sediment background model are chosen as shown in Fig. 1 with \( H_1 = 15.85 m, H_2 = 31.42 m, H_3 = 56.42 m, \) and \( H_4 = 85.7 m \).
The best fit for the upper irregular layer is with the power spectral density of the sound speed and density fluctuations described by a power law distribution:

$$W(k_x, k_y, k_z) = \frac{8\pi \sqrt{\pi} \sigma^2 l_x l_y l_z}{\Gamma(\nu + 3/2)} \frac{\Gamma(\nu + 3/2)}{(1 + k_x^2 l_x^2 + k_y^2 l_y^2 + k_z^2 l_z^2)^{\nu + 3/2}}$$

where $l_x, l_y, l_z$ stand for the correlation lengths in the $x, y, z$ directions, $\sigma$ represents the standard deviation of the fluctuations, $k_x, k_y, k_z$ are the wavenumbers and $\Gamma$ represents the Gamma function. The favorable comparison between theory and experiment is shown in Fig. 2.

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REFERENCES