Quantitative Evaluations of the Effects of the Seabed Sediments on Scattering and Propagation of Acoustics Energy in Shallow Oceans

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LONG-TERM GOALS

To quantitatively understand the physics of propagation and scattering of acoustic waves in shallow waters. The specific and primary goals are the quantitative understanding of the effects of seabed scattering mechanisms (volume fluctuation, bottom and sub-bottom roughness) on the acoustic propagation and scattering, and the effects of poroelastic properties of the sediments on the propagation of acoustic waves.

OBJECTIVES

To develop a universal (forward/inverse) model for the seafloor roughness scattering and the sediment volume scattering.

To accurately measure the propagation and scattering of acoustic waves from the seabed sediments.

To determine how much of the attenuation within sediments is due to the viscosity of pore fluid, the shear wave conversion, and the scattering of acoustic waves.

To accurately measure sediment properties accoustically including permeability, porosity, density, compressional and shear wave velocity and attenuation.

APPROACH

The Yamamoto (1996) theory of sediment volume scattering will be combined with the Jackson et al. (1989) theory of seafloor roughness scattering. This theory will be used for forward and inverse calculations.

The bistatic scattering and backscatter data from the 1996 experiment (sand) and the 1998 experiment (mud) will be analysed to investigate the differences in the effect of sediment type on the acoustic scattering.

The high angular resolution bi-linear acoustic array developed at the Geoacoustics Laboratory (GAL) will be made selfcontained in order to measure the acoustic backscatter and forward scatter in deeper

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waters rougly 100 m (East China Sea and North Atlantic Shelf. In addition, the 800 Hz backscatter array of the Japan Defense Agendy will be used to aquire backscatter 3-D backscatter data at East China Sea and US North Atlantic Shelf as a part of Joint US-Japan Shallow Water Acoustics Experiment.

A new sediment model which includes the effect of macro-pores, and micro-pores in sediments will be developed. This theory will be tested by the existing velocity and attenuation data from cross-well tomography experiments through various sediments. The sediment properties will be extracted.

WORK COMPLETED

The November 1996 forward and back scatter measurements at sandy bottom of Florida Atlantic Shelf have been analyzed and published (Day and Yamamoto, 1999).

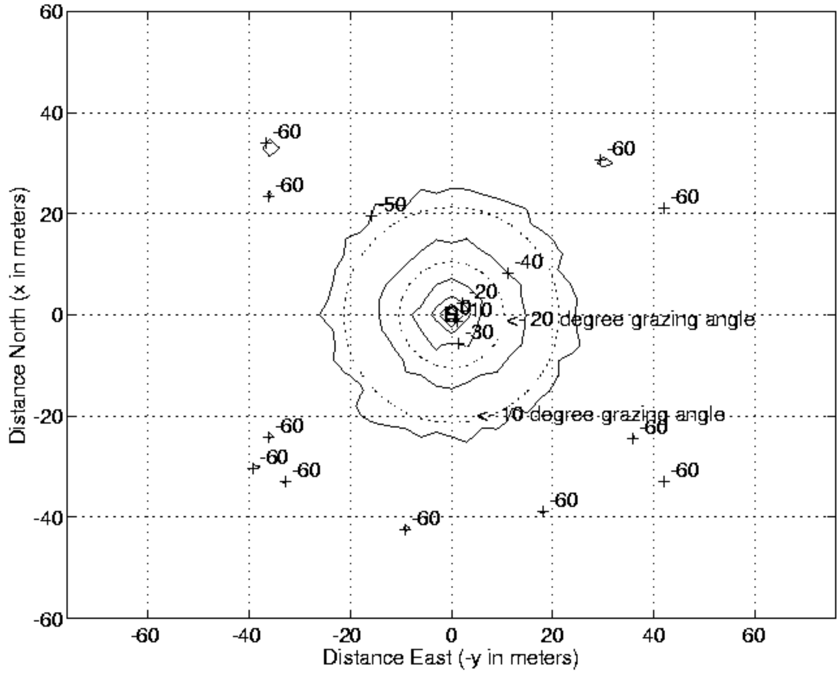
We completed the data analyses of the September 1998 forward and backscatter measurements at silty clay bottom of Gulf of Mexico off Gulf Port (see Figure 1 (a) and (b) and explanations in Result Section).

Because the Japan Defense Agency Research Fleet is not equipped with dynamic positioning, the existing UM-GAL tethered backscatter and forward scatter arrays can not be used in East China Sea (100 m). We are asked by JDA to make our 32-ch scattering arrays totally self-contained to over come this problem. Due to the very limited budget situation and a very short lead time, we are building two units of self-contained source-receiver array with Professor Arata Kaneko's assistance. The sea test of the self-contained scatter sonar units is scheduled in East China Sea in early 2000.

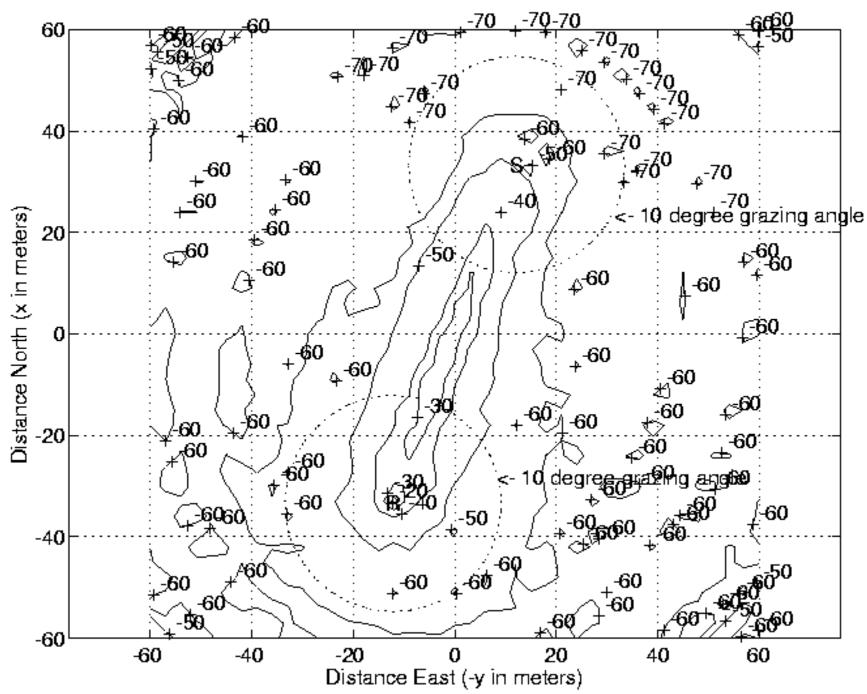
Permeability structures within the sediments were acoustically imaged for the first time and validated by pump test data and core permeability data (Yamamoto, submitted a, b, c).

RESULTS

The tethered 32-channel acoustic array successfully measured the backscatter and forward scatter sterength of a silty clay bottom underlaying a foot thick layer of soupy clay-water mixture in shallow water (11 m) of the Gulf of Mexico near Gulf Port, Mississippi at firequencies 3.75, 7.5 and 15 kHz. The source and receiver array are 3.75 m above seafloor (3.45 m above the soupy clay suspension) and they are separated by 71 m for the forward scattering configuration. The measured15 kHz bottom backscatter strength is shown in Figure 1a. Two circles shown in Figure 1a indicate grazing angles 10 and 20 degrees on the soupy suspension-clay bottom interface. Scattering outside of the 10 degree circle is due to interface roughness and or volume fluctuations in the soupy layer, and inside due to sediment volume fluctuations within the soupy layer and the solid silty clay layer. Backscatter at this site is only slightly azimusally dependent. The measured 15 kHz bottom forward scatter strength is shown in Figure 1b. The forward scatter is mainly due to roughness scattering and or volume scatter within the soupy suspension, except very near the source within 20 m radius where the volume scatter within the solid silty clay layer dominates. Moderat to weak forward scattering (-50 to –30 dB) is mainly concentrated on or near the line connecting the source and the receiver array. From a preliminary inverse analyses of the data in Figure 1a and b, the Mississippi clay bottom has sound speed 1580 m/s, attenuation .15 dB/m/kHz, velocity fluctuations (B = 1.72 e-5, β = 1.3), density fluctuations (B' = 7.83 e-5, β' = 1.3), aspect ratio 6.4, roughness spectrum (w2 = 1 e-5, γ = 2.8). (Read Day and Yamamoto, 1999 for the physical meanings of the symbols). The effect of the soupy layer is included in the roughness. This represents modarate volume fluctuations and weak roughness.



(a) 15 kHz, Bottom Back-scattering Strength



(b) 15 kHz, Bottom Forward-scattering Strength

Figure 1. Measured Bottom Scattering Strength, Gulf of Mexico, Gulf Port, Mississippi

These geoacoustic properties are in agreement with diver observations and previous bottom data. A bottom scattering model includeing the soupy layer must be developed to accurately evaluate the effect of the soupy layer on the backscatter and forward scatter measured and shown in Figure 1.

For most sediments having the sound velocity larger than water sound speed, the backscatter of acoustic energy is nearly totally due to velocity and density fluctuations within the volume for graising angle larger than clitical, and nearly totally due to interface roughness for graising angle smaller than critical. This has been verified from model data comparisons at various sediment bottoms (Rogers and Yamamoto, 1999; Day and Yamamoto, 1999 and this report). This indicates that bottom backscatter measurements are excellent means of characterization of sediment properties and interface roughnesses. Low graizing angle forward scattering is mainly due to the roughness for most sediments (Day and Yamamoto, 1999 and this report).

The permeability images have been extracted from measured velocity and attenuation images within limestone formations (Yamamoto, submitted a and b) and within the near surface marine sedimants (Yamamoto, submitted c). The acuracy of the permeability images have been confiremen by pump tests and cores.

IMPACT/APPLICATIONS

The combined volume (Yamamoto, 1996) - roughness (Jackson et al, 1989) theory is beeing widely accepted for its accuracy and simplicity for various Navy scattering and propagation models (e.g., Odom and Miyamoto, 1999). The inversion of bottom scatter data by this theory provisde rapid and accurate means of bottom characterization.

The UM 32-bilinear array has a high potential of revolutionalizing the measurements of bottom scatter.

The acoustic imaging of the permeability structure within the earth will potentially make a big impact in the geoacoustics and hydrogeology communities for providing accurate and high resolution permeability data badly needed for various modellings.

TRANSITIONS

The Yamamoto (1996) analytical model of sediment volume scattering has been widely used in 6.3 and 6.4 communities for its accuracy and computational advantages (Odom and Miyamoto, 1999).

RELATED PROJECTS

Altan Turgut, NRL, Cross comparisons of the sediment properties extracted from his reflection method with those from our bottom scatter inversions.

Kazuhiko Ohta, Japan Defense Agency, Shallow water propagation and scattering of low frequency acoustic waves.
Arata Kaneko, Hiroshima University, Japan, Extraction of shallow water current structure from high frequency two way propagation of acoustic waves.

Mike Richardson and Kevin Briggs, NRLSSC, Comparisons between their direct measurements with our scattering inversions of sediment properties and roughness.

Darrel Jackson, Bob Odom, Bob Miyamoto, UW-APL, and Andy Rogers, SAIC, General philosophy of acoustic scattering and its applications.

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Yamamoto, T., “Acoustical imaging of permeability structure within carbonate earth,” Geophysics, submitted August 1999b.

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PUBLICATIONS

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PATENTS

"Method of imaging of the permeability and fluid content structure within sediment," U.S. Patent Allowed on October 1, 1999. US Serial No. 09/107,675 filed 6/30/98. Note: this patent is a result of many grants, contracts and author's free time works in the past.