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Measurement of In Situ Acoustic Properties for the ONR Geoclutter Program, Annual Report, Geoclutter Program

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Measurement of *In Situ* Acoustic Properties for the ONR Geoclutter Program

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LONG-TERM GOALS

The long-term objective of the GEOCLUTTER program is to understand the causes and implications of geologic clutter (reverberation) in a geologically well-characterized shallow-water environment. The original field area selected for the GEOCLUTTER program was the mid-outer continental shelf off New Jersey, USA. The New Jersey margin was chosen for the GEOCLUTTER study because the bathymetry and portions of the shallow subsurface of this area had already been mapped in detail as part of an earlier ONR program aimed at understanding the origin of subsurface stratigraphy on continental margins (STRATAFORM). In addition to multibeam bathymetry, 'calibrated' backscatter data (at 95 kHz from the multibeam sonar) was also collected as part of the STRATAFORM program.

OBJECTIVES

The overall scientific objectives of the GEOCLUTTER program are: 1) to understand, characterize, and predict lateral and vertical, naturally-occurring heterogeneities that may produce discrete acoustic returns at low grazing angles (i.e., "geologic clutter") and then; 2) to conduct precise acoustic reverberation experiments at this site to understand, characterize, and potentially mitigate the geologic clutter.

APPROACH

In order to meet these objectives and to properly implement acoustic models for the GEOCLUTTER area, we need to know, or predict, the key acoustic and physical properties throughout the volume of interest (i.e., grain size, density, sound speed, attenuation). The properties of the near-surface seafloor sediments are particularly important. A possible approach to this problem is to use multibeam backscatter data which may provide information on seafloor sediment properties. If remotely−sensed backscatter data can be used to infer seafloor sediment properties, we would have the ability to make quantitative statements about seafloor properties over large areas of the seafloor and thus the ability to address a number of important navy−related problems. The relationship between backscatter and sediment properties remains ambiguous, and as of yet cannot be used as a direct and quantitative predictor of seafloor properties. Attempting to understand the relationship between the multibeam backscatter and the properties of the seafloor is the primary theme of our component of the GEOCLUTTER research program.

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14. ABSTRACT
The long-term objective of the GEOCLUTTER program is to understand the causes and implications of geologic clutter (reverberation) in a geologically well-characterized shallow-water environment. The original field area selected for the GEOCLUTTER program was the mid-outer continental shelf off New Jersey, USA. The New Jersey margin was chosen for the GEOCLUTTER study because the bathymetry and portions of the shallow subsurface of this area had already been mapped in detail as part of an earlier ONR program aimed at understanding the origin of subsurface stratigraphy on continental margins (STRATAFORM). In addition to multibeam bathymetry, ?calibrated? backscatter data (at 95 kHz from the multibeam sonar) was also collected as part of the STRATAFORM program

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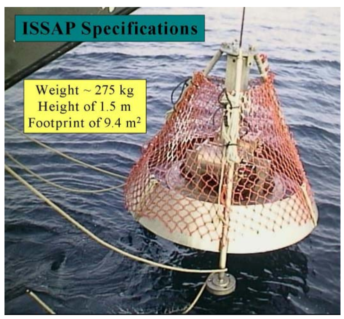
Our initial approach focused on more traditional means of sampling and laboratory measurements to obtain the needed seafloor property information in the GEOCLUTTER area. Given the coarse-grained, sandy nature of the sediment in the region we were concerned that laboratory measurements of certain properties (in particular sound speed and attenuation) on core samples would not reflect *in situ* values as sandy sediments tend to de–water very quickly. Thus, the first phase of our GEOCLUTTER work consisted of the development of a simple and relatively inexpensive device designed to measure, *in situ,* the spatial variability of sound speed and attenuation in near-surface sediments at the GEOCLUTTER site. Our *in situ* measurements were then combined with the data collected from cores (by other investigators – John Goff from the University of Texas and Chris Sommerfield from the University of Delaware) as well as other acoustic data (experiments by Charles Holland from Pennsylvania State and Steve Schock from Florida Atlantic University) to better understand the variability of *in situ* sediment physical and acoustic properties in the GEOCLUTTER area. Subsequent efforts saw the collection of *in situ* physical and acoustic data at the site of the ONR Martha's Vineyard Mine Burial Experiment (see Mine Burial Annual Report) and the most recent work involves the collection of *in situ* data in a very well documented region of Portsmouth Harbor, New Hampshire.

Our second approach has been to attempt to directly estimate seafloor properties from remotely sensed acoustic data. The observations provided by acoustic remote sensing systems, particularly multibeam sonars, are the seafloor depth and the acoustic backscatter, which carry important information about the seafloor morphology and physical properties. These observations can provide valuable data to aid in the difficult task of seafloor characterization. Once we establish a formal mathematical model that links seafloor acoustic properties to these observations, we can attempt to invert the model and estimate the seafloor properties based on the remotely acquired acoustic backscatter. For that we need reliable acoustic backscatter observations and a well-defined acoustic backscatter model. In order to obtain an accurate measurement of acoustic backscatter, it is necessary to radiometrically correct the backscatter intensities registered by the sonar, and to geometrically correct and position each acoustic sample in a projected coordinate system. The second requirement towards the remote characterization of the seafloor is the definition of an acoustic backscatter model, which is an essential tool to link seafloor properties to angular signatures measured by multibeam sonars. In our approach we used the effective density fluid model derived from the Biot theory (Williams, 2001), with some modifications for the calculation to the volume scattering contribution (Fonseca et al., 2002).

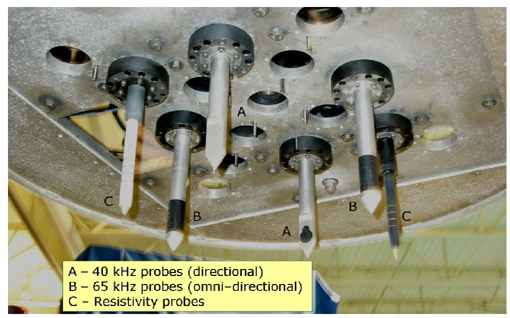
The direct inversion of acoustic backscatter for key physical properties is an ill-posed problem. In order overcome this limitations, we applied a constrained interactive inversion of the model, imposing constraints based on well established inter-relations for sediment physical properties (Hamilton, 1974), and parametric equations from AVO (Amplitude-Versus-Offset) parameters calculated from the backscatter angular response. AVO analysis is normally applied to multichannel seismic reflection data and has been used successfully in the oil industry for the exploration and characterization of subsurface reservoirs. AVO analysis is based on the fundamental observation that seismic amplitudes vary with the offset (angle) between the seismic source and detectors and that this variation can be related to different acoustic properties in the subsurface reflectors (Sarkar and Svatek 1993). In an analogous fashion, multibeam sonars acquire acoustic backscatter over wide range of incidence angles, and the variation of the backscatter with the angle of incidence is an intrinsic property of the seafloor. With appropriate alterations, a similar approach to seismic AVO analysis can be applied to the acoustic backscatter.

WORK COMPLETED

Following successful field work in support of the New Jersey GEOCLUTTER program and the Mine Burial program off Martha's Vineyard, we completed two small field experiments in nearby Portsmouth Harbor (PH) and Little Bay (LB), NH. Field work included sediment sampling and analysis, and *in-situ* measurements with ISSAP (*In-situ* Sound Speed and Attenuation Probe). In our previous field work, the ISSAP (see Fig. 1) was configured with four 65 kHz 'omni-directional' acoustic probes and 'time-of-flight' measurements obtained across five acoustic paths. For this field work, new 40 kHz 'directional' probes were used, which increased the frequency range of the measurements, but limited the number of useable acoustic paths to two. Prior to the field work, the additional probes required modifications to ISSAP's transmit/receive board (improvements to the drive electronics and increased gain control) and updates to the data acquisition program in Labview.



(a)

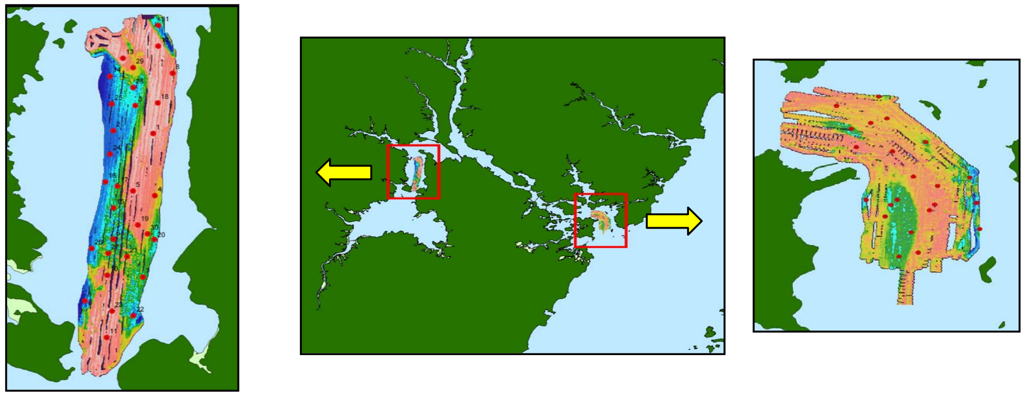


(b)

Figure 1. (a) ISSAP instrument and specifications and (b) underside view of ISSAP showing the configuration of probes.

In October 2003, sediment sampling was conducted from the R/V Coastal Surveyor and ISSAP measurements made from the R/V Gulf Challenger. Sediment samples were obtained with a Van Veen grab sampler (University of Rhode Island (URI), Marine Geomechanics Lab) in Portsmouth Harbor (20 stations) and Little Bay (28 stations). Sub-samples were taken from the grab samples and analyzed using URI's GeoTek multi-sensor core logger (MSCL). Lab measurements including p-wave sound speed (at 250 kHz), gamma ray attenuation (saturated bulk density), magnetic susceptibility, and electrical resistivity were completed at 1 cm intervals on PVC mini-core tubes (5.08 cm ID × 8 cm long). A coarse grain size analysis (5 bins) was performed on all grab samples with an additional hydrometer analysis completed for samples with a mud component exceeding 10%.

Measurements of *in-situ* sound speed and resistivity (porosity) were completed with ISSAP configured with two orthogonal matched pairs of transducer probes operating at frequencies of 40 and 65 kHz (see Fig. 1b). Measurements were obtained in both Portsmouth Harbor (13 stations) and in Little Bay (23 stations). In April 2004, ISSAP measurements were repeated in Little Bay (24 stations) using the same probe configuration (40 and 65 kHz probes). Additional measurements with ISSAP configured using matched 65 and 100 kHz probes were obtained in Little Bay (18 stations).



(a) (b) (c)

Figure 2. Piscataqua River Watershed, Portsmouth, NH. ISSAP stations were selected to represent a range of sediment types and are denoted with a red symbol. (a) Little Bay field area shown (defined) with Simrad EM3000 (300 kHz) multibeam backscatter, (b) Overview showing relative location of the Portsmouth Harbor and Little Bay field areas, and (c) Portsmouth Harbor field area (defined) shown with Simrad EM3000D (300 kHz, dual head) multibeam backscatter.

Acoustic remote sensing data was also acquired in Little Bay, New Hampshire (Fig. 2). The data were collected with a Simrad EM3000 multibeam sonar which operates at 300KHz, and forms 127 beams over an angular sector of 130 degrees. The survey mapped water depths from 6 to 24m, providing swath bathymetry and high-resolution time-series of acoustic backscatter. The analysis started with the backscatter time series stored in raw Simrad datagrams, which were then corrected for radiometric and geometric distortions. Radiometric corrections included the removal of the time varying and angle varying gains applied during acquisition, calculation of the true grazing angle with respect to a bathymetric model, and correction for footprint size (Fonseca and Calder 2005). Additionally, it was necessary to remove the Lambertian correction and the near nadir time-varying-gain compression that are applied by the manufacturer to the backscatter time-series during acquisition. The radiometrically and geometrically corrected backscatter was then compared to the predictions of the mathematical model. The inversion of the model for acoustic seafloor properties was accomplished by means of the AVO analysis technique.

AVO analysis was applied to a seafloor patch, which was defined as the stack of 30 consecutive sonar pings. Each stacked angular response (Figure 3) defines two distinct seafloor patches, one for the port side and another starboard side. The stacking of consecutive pings reduces the speckle noise common to any acoustic method, and is the swath-sonar equivalent of the seismic stacking. This stacking process limits the spatial resolution of the AVO analysis but is essential to noise reduction in the acoustic backscatter. After the stacking, the corrected backscatter angular response is divided to three intervals: near, far and outer ranges. The near range includes grazing angles from 90° to 65°, the far range from 65° to 35°, and the outer range from 35° to 5°. In the near range, the mean backscatter, the slope, and the 80° intercept of the stacked backscatter are calculated and stored as AVO attributes (Figure 3). The near-intercept is calculated at 80° in order to avoid the nadir instability, very common in sonars. In the far range, the attributes of mean backscatter, slope and the intercept at 55° are calculated. In the outer range, only the mean backscatter is stored as an attribute, as it has a correlation to the critical angle of reflection defined by the sound-speed ratio between the water and the sediment. One important AVO parameter used to characterize the backscatter angular response is the fluid-factor.

According to the backscatter model, this attribute responds to volume heterogeneities, more specifically the amount of free fluid, normally gas, in the sediment structure (Fonseca et al., 2005).

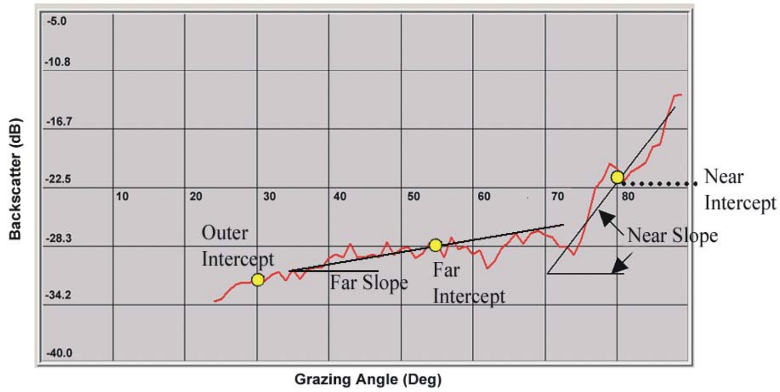


Figure 3. Stacked backscatter angular response measured by a Simrad EM3000 multibeam sonar, with some of the AVO parameters.

The inversion of the acoustic backscatter model, which in principle is an ill-posed problem giving multiple solutions and instability, was constrained by the adjustment of the AVO parameters and not by the adjustment of the model parameters. Based on the calculated AVO attributes and the constrained interactive inversion of the acoustic backscatter model we can estimate the acoustic impedance, grain-size and the roughness of the insonified area on the seafloor (Figure 4).

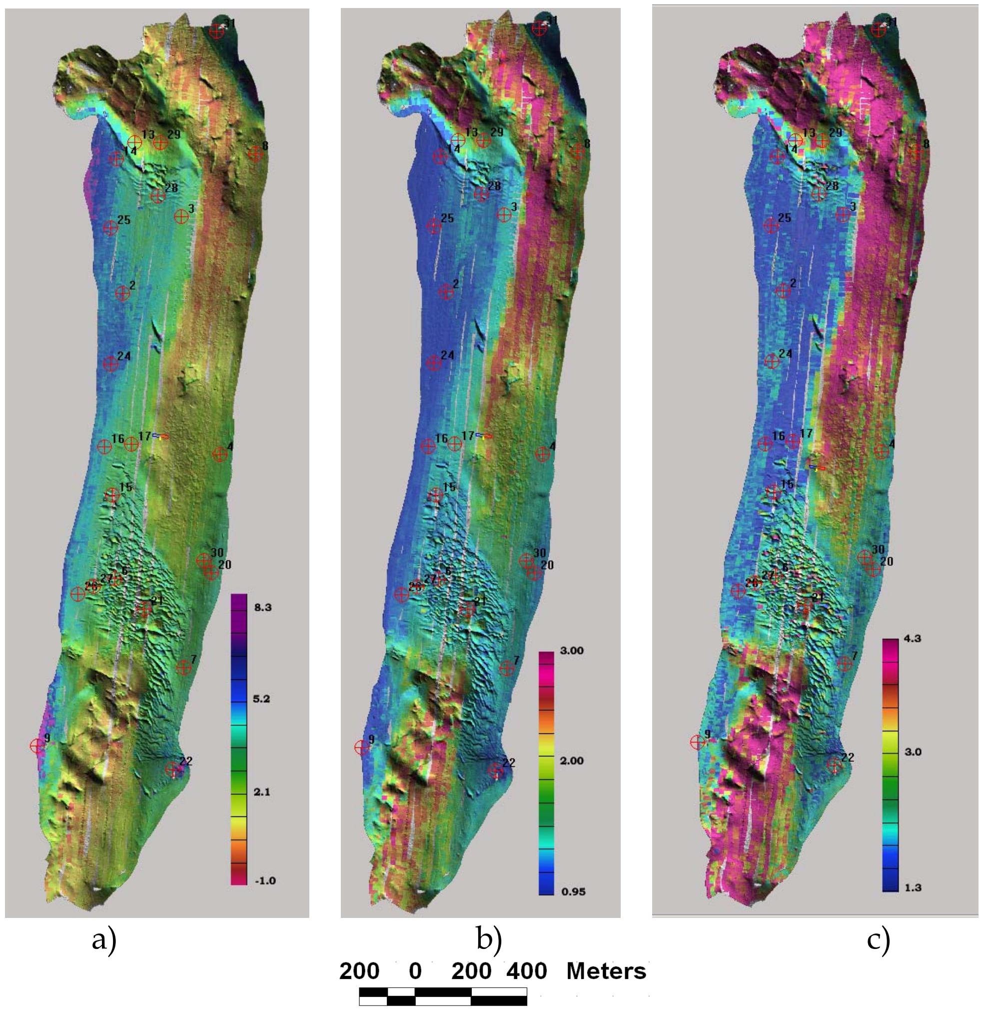


Figure 4 – Results of the model inversion. The inverted parameters are represented by a color scheme draped over the sun-illuminated bathymetry. a) Sediment grain size in ϕ; b) Impedance ratio; c) Roughness in cm.

RESULTS

Sound speed dispersion was observed at a majority of stations excluding the stations with a sound speed approximately that of the overlying seawater. Initial comparisons indicate that the magnitude of the sound speed dispersion is related to the mean grain size. The grain size analysis conducted by URI was initially limited to five grain size bins which did not provide an accurate estimate of the grain size distribution. URI recently completed hydrometer analysis of the mud component (for stations with greater than 10% mud fraction).

The remotely estimated impedance ratio, obtained from the AVO analysis, when compared to the *in-situ* (ISSAP) measurements of sound speed ratio at a frequency of 40 kHz., showed a strong correlation (Figure 5) indicating the potential of this approach for the remote characterization of seafloor properties. To further substantiate this method, additional field work is required, including a larger sample of sediment types, better observations, and radiometrically calibrated and geometrically corrected backscatter.

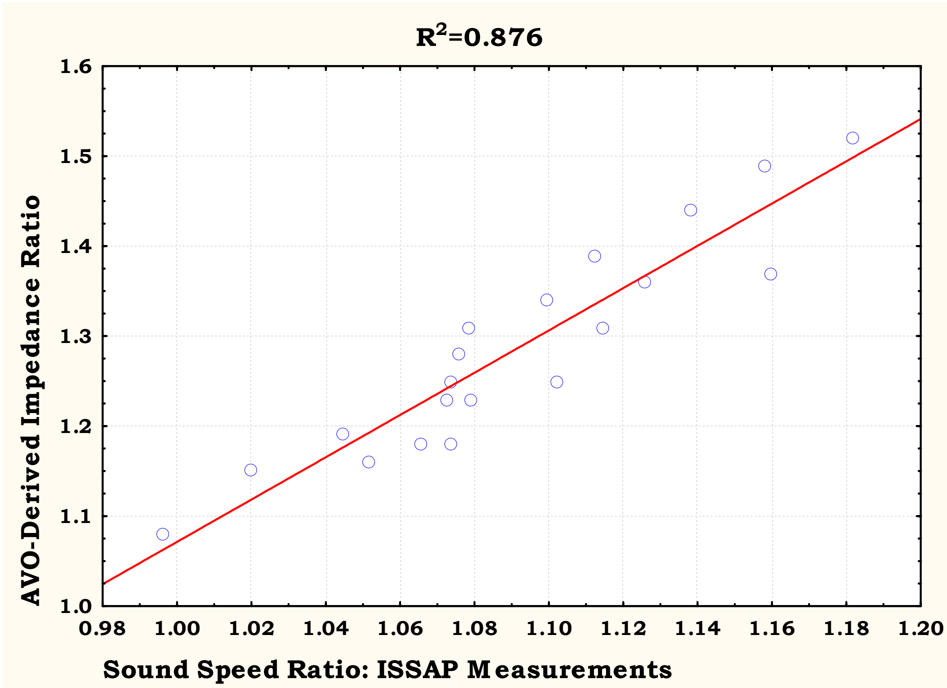


Figure 5. Estimated impedance ratio as a function of ISSAP sound speed ratio at 40 kHz.

IMPACT/APPLICATIONS

The ISSAP has provided a simple and quick way to establish the lateral distribution of sound speed and attenuation variations within the Geoclutter area. These measurements are being compared directly to backscatter values from the multibeam system and to the predictions of impedance and attenuation made from the Chirp Sonar by Schock. They also provide information on the range of natural variability that is very relevant to other Navy programs (e.g., Capturing Uncertainty DRI and Mine Burial Program – where it was used).

The work described above has established the groundwork for the development of a robust seafloor characterization approach that will allow the estimation of critical seafloor properties from remotely derived acoustic data.

TRANSITIONS

Data requested by Chris Jenkins for incorporation into global sediment property database. Geocoder (mosaicing) algorithm being transitioned into commercial sector and other research labs.

RELATED PROJECTS

Uncertainty DRI, Mine Burial DRI

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