Measurement of *in situ* Acoustic Properties for the ONR Geoclutter Program

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Award #N00014-00-1-0821
http://www.ccom.unh.edu/

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 field area selected for the GEOCLUTTER program is 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.

SCIENTIFIC 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 the 95-kHz multibeam backscatter data collected in the region, 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 however, and cannot yet 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 this component of our GEOCLUTTER research program.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE **Measurement of in situ Acoustic Properties for the ONR Geoclutter Program**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of New Hampshire,,Center for Coastal and Ocean Mapping,,Durham,,NH,03824**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

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 field area selected for the GEOCLUTTER program is 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.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

In light of the fact that we have not yet successfully been able to produce accurate estimates of seafloor properties from remotely sensed acoustic data, our initial proposal fell back 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 could then be 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 future work will involve the collection of *in situ* data in a very well documented region of Portsmouth Harbor, New Hamphshire.

WORK COMPLETED TO DATE:

In support of the Geoclutter program, we have developed, built, and deployed a relatively inexpensive, robust, small-ship-deployable device (ISSAP – *In situ* Sound Speed and Attenuation Probe) for measuring sound speed and attenuation in near-surface sediments. Our objective was to design and deploy a device that would specifically address the question of the spatial variability of seafloor sediment properties by rapidly making multiple measurements of sound speed and attenuation in near-surface sediments. Our concept was to design an instrument that was like a box-corer and that could rapidly make multiple measurements of *in situ* properties by simply "pogo-ing" on the bottom and thus cover a relatively large area of the seafloor in a short period of time. Measurements of *in situ* acoustic properties are particularly critical in the sandy sediments off New Jersey as these sediments tend to quickly dewater making laboratory measurements difficult.

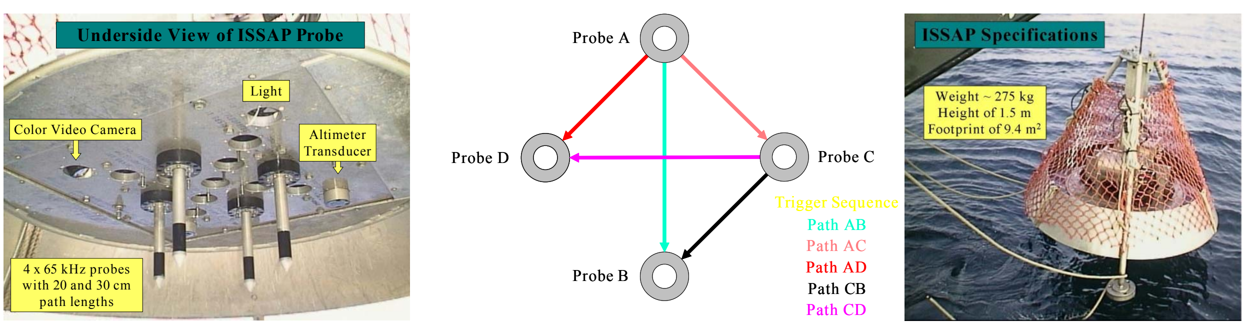


Figure 1. Underside view of ISSAP showing orientation of probes (left),diagram showing 5 paths used for sound speed and attenuation measurement (middle) and photo of tripod and probe assembly (right).

The ISSAP uses four 2.54 cm (diameter) by 30 cm long probes that are inserted 15 cm into the seafloor by 250 kg of reaction weight attached by armored coaxial cable to a free-swinging inner frame within a protective outer tripod. This design, in combination with articulated tripod feet, allows the probes to be inserted vertically on slopes up to 20 degrees (Fig 1). The transducer probes are mounted on an inner frame assembly with precision-machined Delrin ^{TM} collars designed to decouple the acoustic signals from the frame. The original suite of probes operate at frequencies of either 65 or 100 kHz. Probe separation can be adjusted in 10 cm increments from 10 to 60 cm. Typically the probes are arranged in a square pattern with nominal path separations of 20 and 30 cm (Fig. 1). An onboard computer and topside electronics control the paths selected and the number of measurements per path. A typical deployment involves measurements across five paths including both long (30 cm) and short (20 cm) paths. In addition to the acoustic probes, the ISSAP also has a color video camera that provides imagery of the seafloor and the probes as they penetrate, a 65 kHz altimeter to independently monitor height off the bottom, and temperature, pressure, pitch, roll, and heading sensors to monitor the stability and orientation of the platform. Finally, a bottom sense switch provides yet another indication of the platform's height above the bottom. This past year, two resistivity probes have been added to the ISSAP allowing *in situ* sediment porosity to be estimated through the application of Archie's Law.

A typical sampling station consists of two bottom-water measurement cycles (150 measurements each) and two sediment measurement cycles (150 measurements each) for a total of 600 independent measurements of acoustic travel time over 5 independent paths with different separations. Each measurement cycle is completed in less than one minute; with the time to complete sampling an entire station on the order of five minutes and producing about 300 Mbytes of data.

Travel times are determined by several methods and converted to sound-speed through a calibration process; the relative amplitude of the received waveforms over the different path-lengths as well as the spectral ratio (or difference) between the seawater-received waveform and the sediment- received waveform are used to determine *in situ* attenuation values. Details of the analytical procedures are presented in Kraft et al. (2002).

Work completed in 2003 includes the construction of resistivity probes (for porosity determinations), the construction of lower frequency probes (target frequency of less than 40 kHz), the deployment of the system in the Martha's Vineyard Mine Burial Experiment field area and the application of the results from the ISSAP to explore the viability of several competing geoacoustic models (see below).

RESULTS:

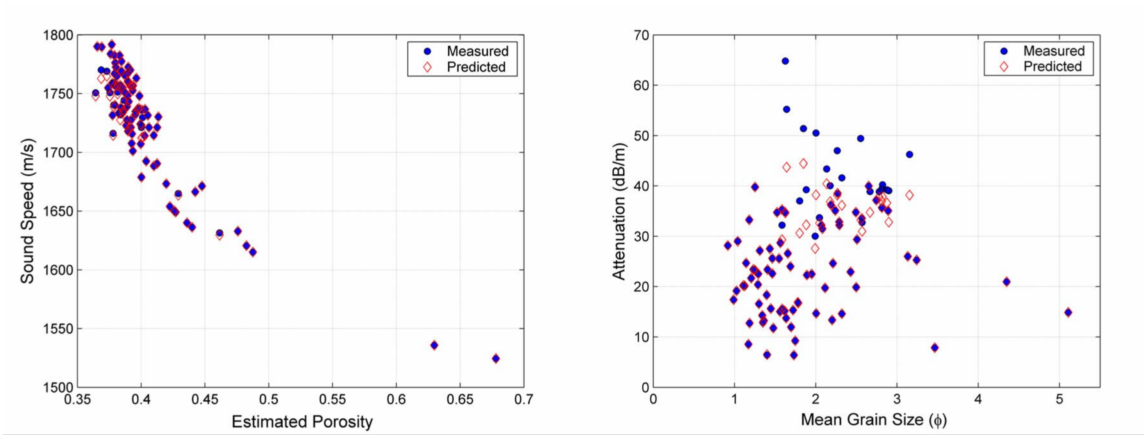
The ISSAP was deployed in the GEOCLUTTER area off New Jersey on the *R/V Cape Henlopen* between 30 July and 5 August, 2001. The system performed flawlessly recovering water column and sediment data at 99 stations selected to represent a range of seafloor backscatter types over an area of approximately 1300 sq. km. More than 40 gigabytes of digital data were collected as well as more than 20 hours of video allowing us to understand the true local variability of sound speed and attenuation in the GEOCLUTTER area. A full discussion of the system deployment and initial results can be found in Mayer et al. (2002)

More than 58,000 individual measurements were made over the 1300 sq. km area. The overall accuracy of measurements was +/- 1 to 2 m/sec for sound speed and +/- 1 dB/m for attenuation. Across the entire area the mean speed of sound in seawater was 1500.8 m/sec with a range of less than 10 m/sec, within the expected change due to variations in bottom-water properties. Over the 1300 sq km area, the sound speed in the sediment varied from 1524 m/sec to 1801 m/sec and attenuation ranged from 10 to 71.3 db/m at 65 kHz. Looking at the spatial scales of variability, we found sound speed varying over 200 – 300 m/sec and attenuation varying by about 60 dB/m over length scales of 10's of kms; sound speed varied by about 100 m/sec and attenuation by about 25 dB/m over spatial scales of less than 1 km and; sound speed varied by about 5 m/sec and attenuation by about 3 dB/m over spatial scales of less than 1 meter (except where there were discrete shells or cobbles in the path). The group of stations with the highest attenuation coefficients (k = 0.8 – 0.9 dB/m·kHz), had the largest weight percent of fine sand (.175 to .25 mm) as well as a higher percentage of coarse grains with diameters greater than 4 mm. In contrast, the stations with the lowest attention coefficients had the highest weight percent of medium sand (.25 to .35 mm). These stations had grain size distributions indicating relatively, well-sorted sediments (mostly homogeneous, medium grained sands), while the high-attenuation stations contained a mixture of course and fine grained sediments.

Similar results were found in the Martha's Vineyard Mine Burial Experiment area where more than 62,000 discrete measurements were made representing more than 30 Gigabytes of data. Even in this region of relatively limited sediment diversity, the sound varied from 1575 m/sec to 1806 m/sec and attenuation from 6.5 to 59.3 dB/m at 65 kHz. As in the N.J. margin area, the greatest variation in both sound speed and attenuation appears to be associated with the finer-grained sediments. Details can be found in the Mine Burial Experiment Annual Report.

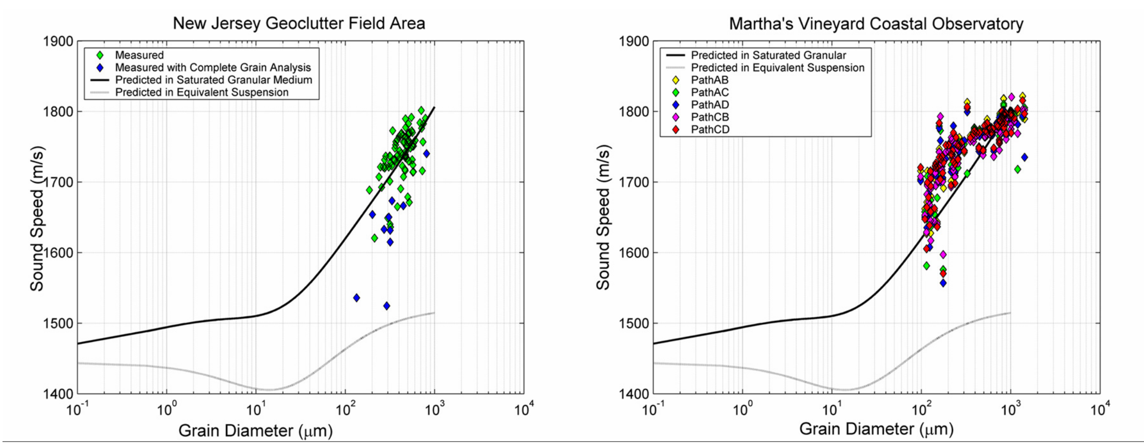
Measured velocity and attenuation from the Geoclutter field area were compared to Biot-Stoll model predictions using an optimization algorithm. An inherent difficultly in using this model is that it requires the input of 13 parameters describing properties of the sediment and saturating pore fluid. Obtaining good estimates for sediment properties proved quite difficult (pore fluid properties are easily found in the literature). Because the measured porosity values were found to not be reliable, the approach taken was to use the measured sound speed to estimate porosity and then compare the attenuation predicted by the model with the measured attenuation. Empirically derived equations were used to estimate permeability (Kozeny-Carman equation predicts permeability as a function of grain size diameters) and pore size. The remaining input parameters were obtained from published literature. A constrained (range of porosity was limited), non-linear optimization was used and produced excellent agreement between the measured and predicted sound speed; however, there were large discrepancies in the attenuation (Fig 2). The model parameters of stations with similar measured attenuation, but not predicted attenuation, were examined. It was found that the estimated permeability for these stations differed by more than an order of magnitude. The optimization was performed a second time using both the measured sound speed and attenuation as inputs to estimate porosity and permeability at each station. Convergence of the optimization was sensitive to initial values; therefore, the Kozeny-Carman permeability was used as the initial value. Varying the permeability resulted in the optimization converging at more than two-thirds of the stations (except those stations with the highest measured attenuation – stations with very fine sand and poorly sorted sediments). New values of permeability were in close agreement with values found in the literature. The primary result of this exercise was that loss mechanisms incorporated into the Biot model (frictional losses at the grain contacts and viscous dissipation due to the relative motion between the pore fluid and the frame) were able to account for the values of measured attenuation.

We also looked at the Buckingham model which considers unconsolidated sediments to be a two-phase medium consisting of mineral grains and seawater. Unlike the Biot model, the unconsolidated sediments possess no rigid frame. The medium is treated as a bulk fluid in which sound propagation is governed by internal losses arising at grain-to-grain contacts only and does not consider viscous losses. This model is simple to implement, i.e., the porosity and the density are expressed as algebraic functions of the grain diameter (in microns, not phi units). Model comparisons were done with the NJ and MV sound speed data (attenuation comparisons not yet complete). Considerably good agreement was achieved with the NJ data, more so for the stations with coarser grained sediments than those with finer grained sediments (Fig 3a). Including the silt/clay analysis into the mean grain diameters provided little improvement. MV sound speed data was in good agreement with the model for the coarse grain sediments but deviated from the model quite strongly for the medium to fine sands (Fig 3b). The cause of this intriguing deviation will be investigated further.



a.) b.)

***Figure 2. Results of Biot model showing a.) convergence of measured sound speed with model predictions and b.) convergence of predicted attenuation with measurements using measured sound speed and attenuation as inputs and estimating porosity and permeability*.**



a.) b.)

Figure 3. Results of Buckingham model for a.) Geoclutter field area off New Jersey and b.) Mine Burial field area off Martha's Vineyard. NJ sound speed measurements are station averages and show good agreement with the Buckingham model except for stations with high clay content. MV sound speed measurements are path averages and tend to deviate from the model except for the stations with coarser grained sediment.

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 will play a key part in the overall development of robust seafloor characterization approaches, particularly through helping to better constrain the relationship of high-frequency backscatter to seafloor properties. It will also provide critical information on the relationship of *in situ* properties to those made in the laboratory as well as those extracted remotely from the inversion of seismic (Chirp Sonar) data.

TRANSITIONS:

Data requested by Chris Jenkins for incorporation into global sediment property database

RELATED PROJECTS:

Uncertainty DRI, Mine Burial DRI

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