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Seafloor Characterization from Spatial Variation of Multibeam Backscatter vs. Grazing Angle

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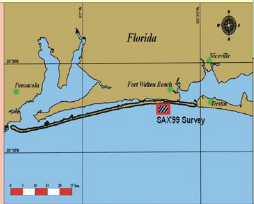
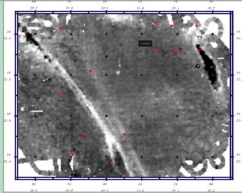
Abstract

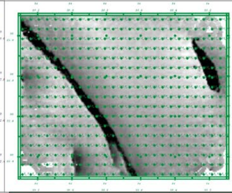
Backscatter vs. grazing angle, which can be extracted from multibeam backscatter data, depend on characteristics of the multibeam system and the angular responses of backscatter that are characteristic of different seafloor properties, such as sediment hardness and roughness. Changes in backscatter vs. grazing angle that are contributed by the multibeam system normally remain fixed over both space and time. Therefore, they can readily be determined and removed from backscatter data. The variation of backscatter vs. grazing angle due to the properties of sediments varies from location to location, as sediment characteristics change. The sediment component of variability can be inferred using the redundant observations from different grazing angles in several small pieces of seafloor assuming that the sediment property is uniform in any given piece of seafloor yet vary from one piece of the seafloor to another. Thanks to the multibeam survey (Roger Flood, State University of New York) at SAX 99 Project sponsored by Office of Naval Research (ONR), which had 800% coverage in most of the survey area; there is a data set, which is suitable for investigating seafloor characterization. The investigation analyzed the spatial variation of the backscatter vs. grazing angle and compared that with ground truth sediment data.



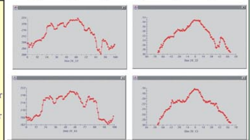
A high-frequency acoustic experiment (SAX99) was performed at a site 2 km from shore on the Florida Panhandle near Fort Walton Beach in water of 18-20 meter depth. The goal of this experiment was to study acoustic backscattering from the seafloor sediment, acoustic penetration and propagation into and within the sediment.

In this research, the 6.9 gigabytes raw multibeam data were first cleaned using an automated outlier detection algorithm (Tianhang Hou, Lloyd Huff and Larry Mayer, 2001). The surveyed area was then divided into 52X78 equal rectangular working cells (4056), with the sides of each cell being about 20 meters. The two background images on the right were created from the nadir and off-nadir beams. The off-nadir beams were the source for the right most of the two background images.

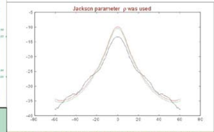




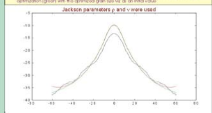
Backscatter vs. grazing angle relationships for each cell were computed by averaging backscatter data of corresponding beam numbers from different survey lines. Corrections were made for systematic asymmetric and skew effects on the backscatter vs. Grazing angle, caused by multibeam system hardware or software as well as system installation.



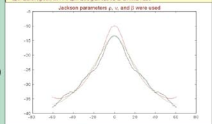
Different subsets of Jackson (1986) parameters (ρ, ν, β, γ, δ, ?,) were used to optimize the agreement between predicted and observed backscatter vs. grazing angles. Progressing from top to bottom the graphs show the optimal match between the model and observed values, based on which model parameters were varied.



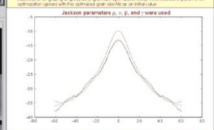
Backscatter vs. grazing angle (black), grain size optimization (red), one Jackson's parameter optimization (green) with the optimized grain size Mz as an initial value



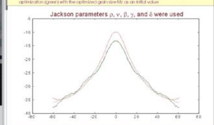
Backscatter vs. grazing angle (black), grain size optimization (red), two Jackson's parameters optimization (green) with the optimized grain size Mz as an initial value



Backscatter vs. grazing angle (black), grain size optimization (red), three Jackson's parameters optimization (green) with the optimized grain size Mz as an initial value



Backscatter vs. grazing angle (black), grain size optimization (red), four Jackson's parameters optimization (green) with the optimized grain size Mz as an initial value



Backscatter vs. grazing angle (black), grain size optimization (red), five Jackson's parameters optimization (green) with the optimized grain size Mz as an initial value

Grain size optimization

Grain size is measured in logarithmic unit and defined as $M = -\log_2 \frac{d}{d_0}$

Jackson's parameters, can be expressed as

Density ratio: $\rho = F_1(M_z)$;

Sound speed ratio $\nu = F_2(M_z)$;

Spectral strength $\beta = F_3(M_z)$;

Spectral exponent $\gamma = 3.25$;

Loss parameter $\delta = F_4(f, \rho, M_z)$.

Computation of backscatter cross section

Kirchhoff model $\sigma_{kr}(\theta) = K(\theta, \rho, \nu, \beta, \gamma, \delta)$

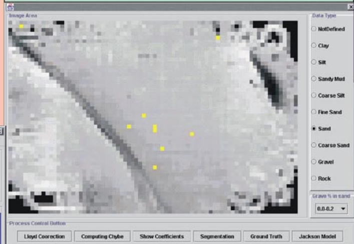
Composite roughness $\sigma_{cr}(\theta) = CR(\theta, \rho, \nu, \beta, \gamma, \delta)$

Interpolated $\sigma_{mr}(\theta) = f(x)\sigma_{kr}(\theta) + [1 - f(x)]\sigma_{cr}(\theta)$

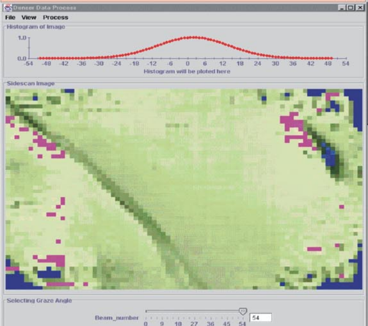
Optimization by Hook algorithm

$\varepsilon_j = \sum_i (\sigma_{mr}(\theta_i) - BS(\theta_i))$

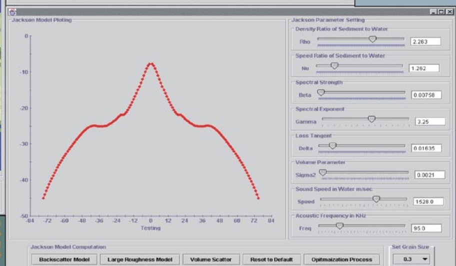
The data processing included steps in which the beam pattern correction algorithm was applied; Lambertion correction applied by sonar manufacture was removed; Chebyshev polynomial coefficients were computed for image segmentation; unsupervised K-means algorithm was implemented using the Chebyshev coefficients as the elements in feature space; ground truth information such as sediment type and the gravel parentage in sand were displayed and analyzed with the backscatter image; and finally Jackson's backscatter model was used to compute the cross section values by interactively changing the model parameters.

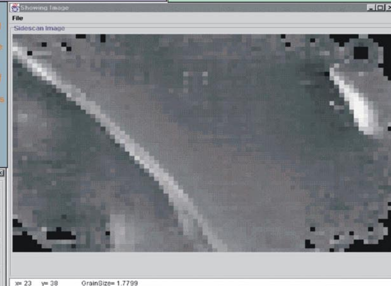


Jackson's composite roughness model and sediment volume scattering model were implemented as the function of grain size, and six parameters of the model. Graphic interface software was designed for displaying predicted backscatter cross-section data from Jackson's model.



Graphic interface software was developed in order to easily evaluate the spatial variation of backscatter vs. grazing angle. With a mouse click, images based on different subsets of the data can be compared throughout the survey area. The subsets were created using specific beam numbers. Images for different beam subsets show significant variations between nadir and off-nadir beams.





Grain size optimization was performed by using Hooke and Jeeves's (1963) direct search algorithm that searches for a local minimum, beginning from the starting guess of constant grain size value for entire area. The brighter areas represent the smaller grain sizes. The cross correlation between the optimized grain size and the 22 ground truth samples of grain size is 0.86.

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Conclusion

This investigation has employed Jackson's compact roughness model and Hooke's constrained optimization algorithm. The spatial variations of sediment grain size, density and velocity as well as roughness parameters (β, γ) have been investigated in order to better understand the agreement between backscatter observations and acoustic modeling, based on available ground truth information. Variations of multibeam backscatter vs. grazing angle provide an interesting interpretation of the images in light of seafloor characteristics, which were derived from ground truth data