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

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

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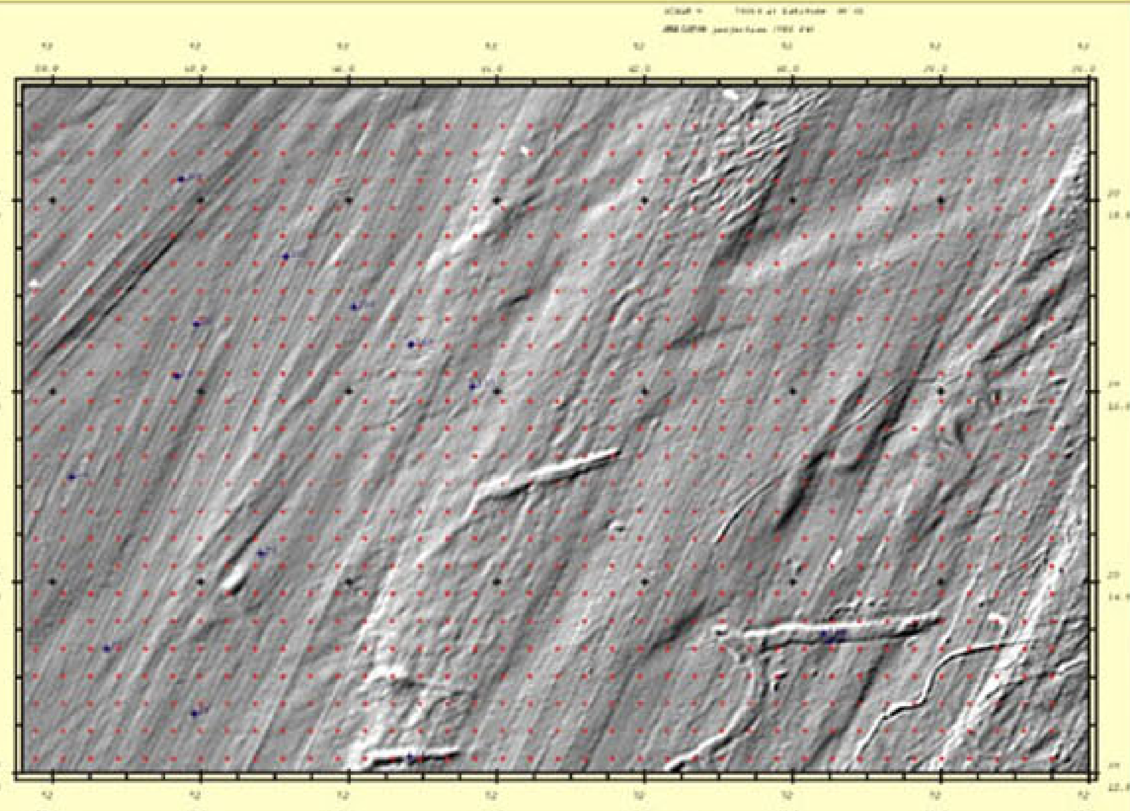
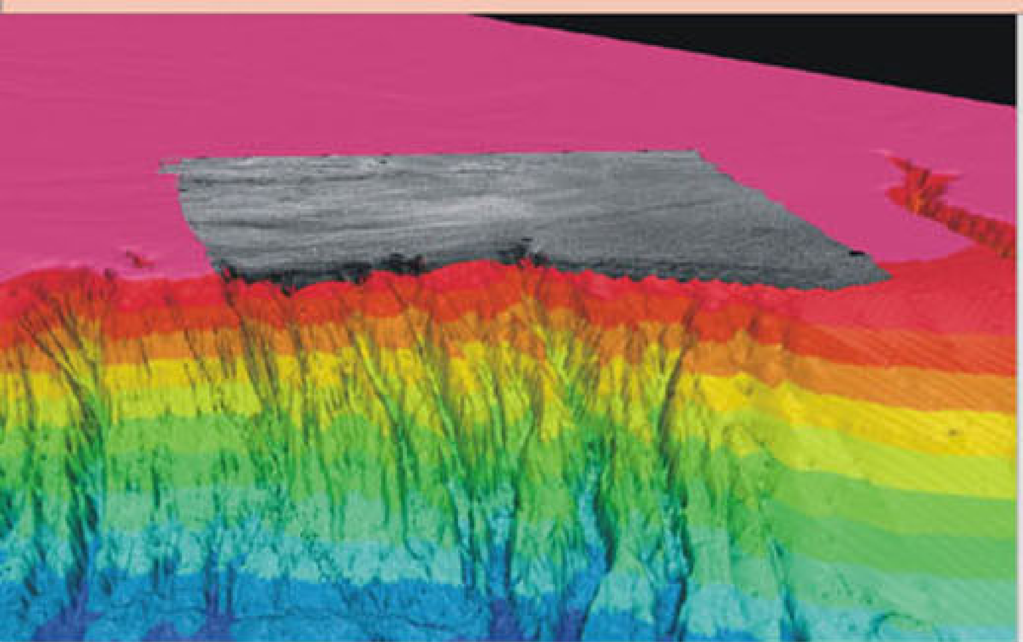
Abstract

The behavior of multibeam sonar backscatter data as a function of grazing angle1 depends on the characteristics of the multibeam system, the geometry of ensonification, and the properties of the seafloor, 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 component of backscatter vs. grazing angle due to the properties of the seafloor varies from location to location, as the sediment changes. The sediment component of variability can be inferred using redundant observations from different grazing angles in several small sections of seafloor assuming that the sediment property is uniform over that section.

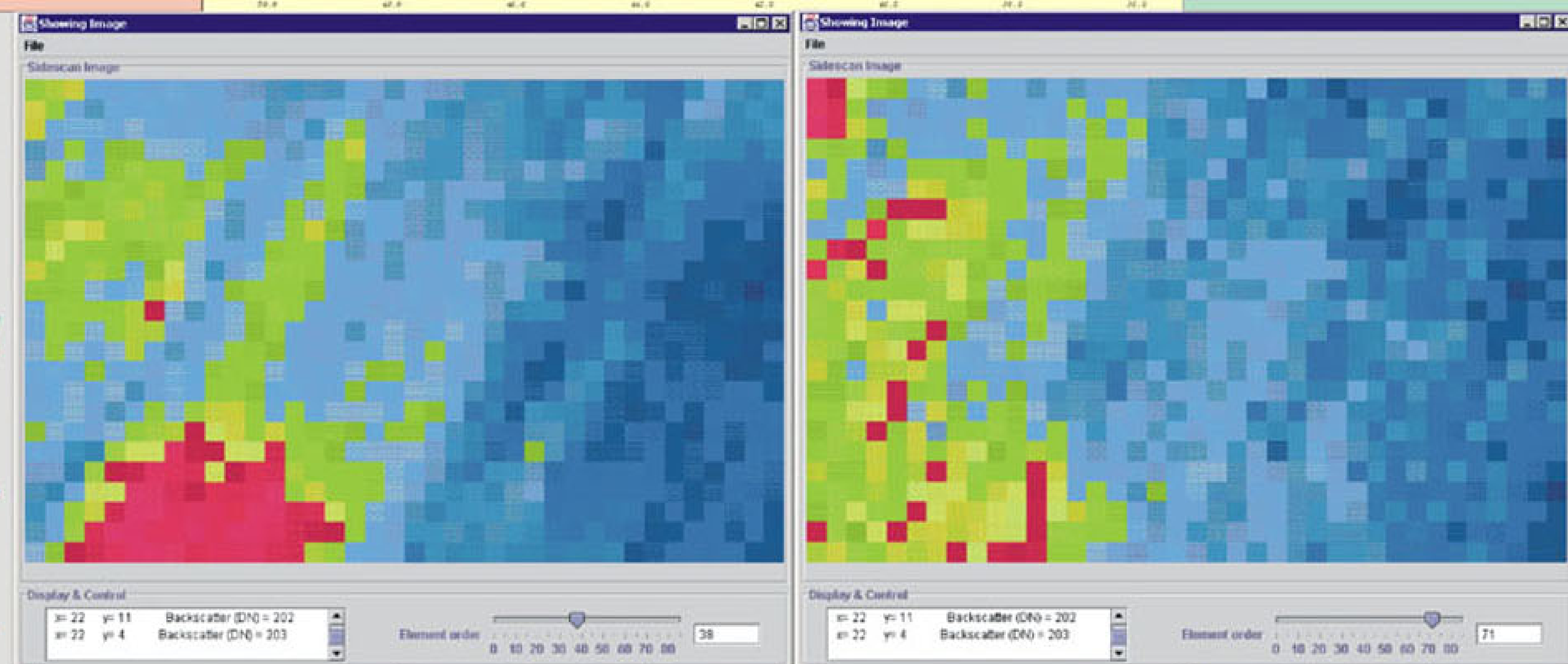


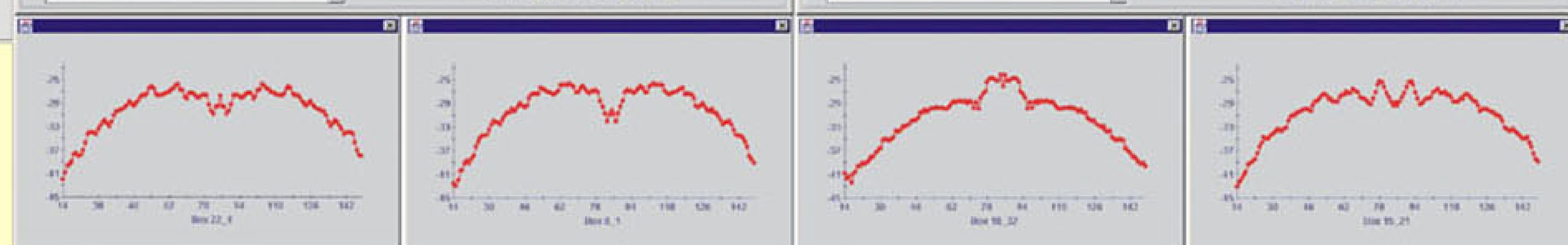
In this research, the raw multibeam data were first cleaned using an automated outlier detection algorithm (Hou, Huff and Mayer, 2001). The selected area (subset) was then divided into 24X38 equal rectangular working cells (912), with the sides of each cell being about 500 meters. The background image of 25-meter resolution was created from the bathymetric data. The blue dots represent the locations of available ground truth stations (ONR Geoclutter Project).



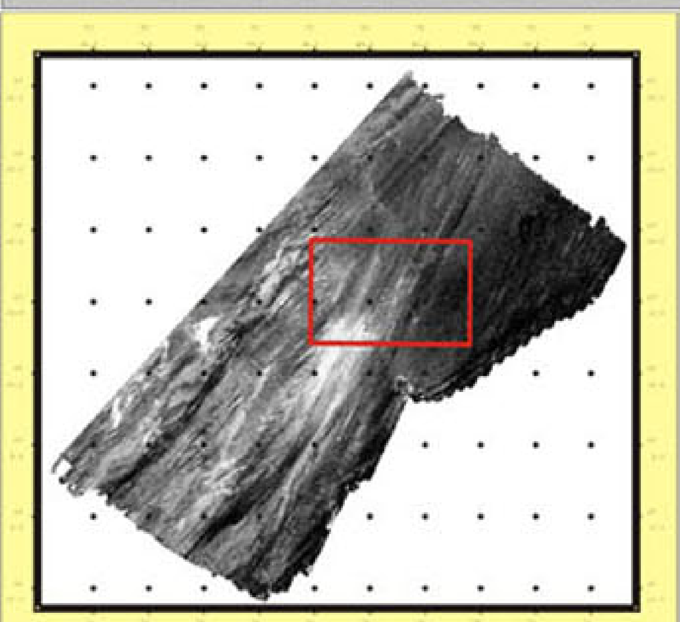
The multibeam data were collected using a Simrad EM1000 system, which provides both bathymetry and backscatter at 95 KHz. A small subset (13 x 20 km) of the NJ multibeam survey was selected as the focus of this research

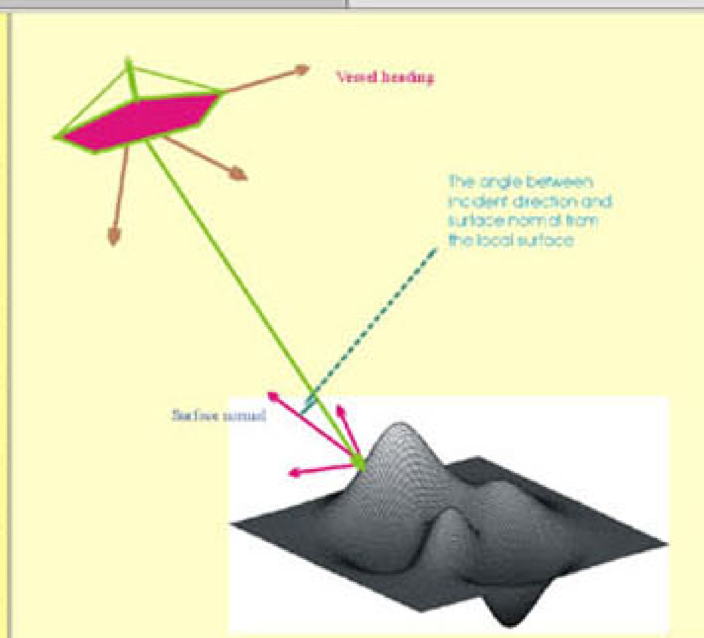
Our study area is the mid-outer continental shelf off the New Jersey. The data used were collected during two field programs: The STRATAFORM New Jersey margin swath-mapping survey (1996) and Geoclutter program (2001), both sponsored by the Office of Naval Research (ONR). The backscatter imagery was draped on the DTM surface by the visualization software Fledermaus.





A graphic interface was developed to ease evaluation of the spatial variation of backscatter strength (BS) 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 from specific grazing angles. These images show significant variations between nadir and off-nadir beams. Variations apparent in the images may provide some indication of the sediment (or seafloor) characteristics, which can be compared to ground truth data, such as sediment velocity, attenuation and grain size.





A surface normal can be defined by $[p = \frac{\partial f(x,y)}{\partial x}, q = \frac{\partial f(x,y)}{\partial y}, -1]$ at the point {X, y} on the surface $z=f(x,y)$. The pair (p, q) represents the surface orientation at {X, y}.

The bi-quadric fit involves finding the six coefficients of the polynomial

$$z = f(x,y) = a_0 + a_1 x + a_1 y + a_3 x^2 + a_4 xy + a_5 y^2,$$

The weighted least squares fitting was used to determine vector $\mathbf{a} = \{a_0, a_1, a_2, a_3, a_4, a_5\}$

$$\mathbf{a} = (A^T P A)^{-1} A^T P z$$

Transforming from the geographic coordinates to the vessel frame coordinates:

$$\begin{bmatrix} a_0' \\ a_1' \\ a_2' \\ a_3' \\ a_4' \\ a_5' \end{bmatrix} = \begin{bmatrix} a_0 \\ a_1 \cos\theta - a_2 \sin\theta \\ a_1 \sin\theta + a_2 \cos\theta \\ a_3 \cos^2\theta + a_5 \sin^2\theta - a_4 \cos\theta \sin\theta \\ 2\cos\theta \sin\theta (a_5 - a_3) + a_4(\cos^2\theta - \sin^2\theta) \\ a_3 \sin^2\theta + a_5 \cos^2\theta + a_4 \cos\theta \sin\theta \end{bmatrix}$$

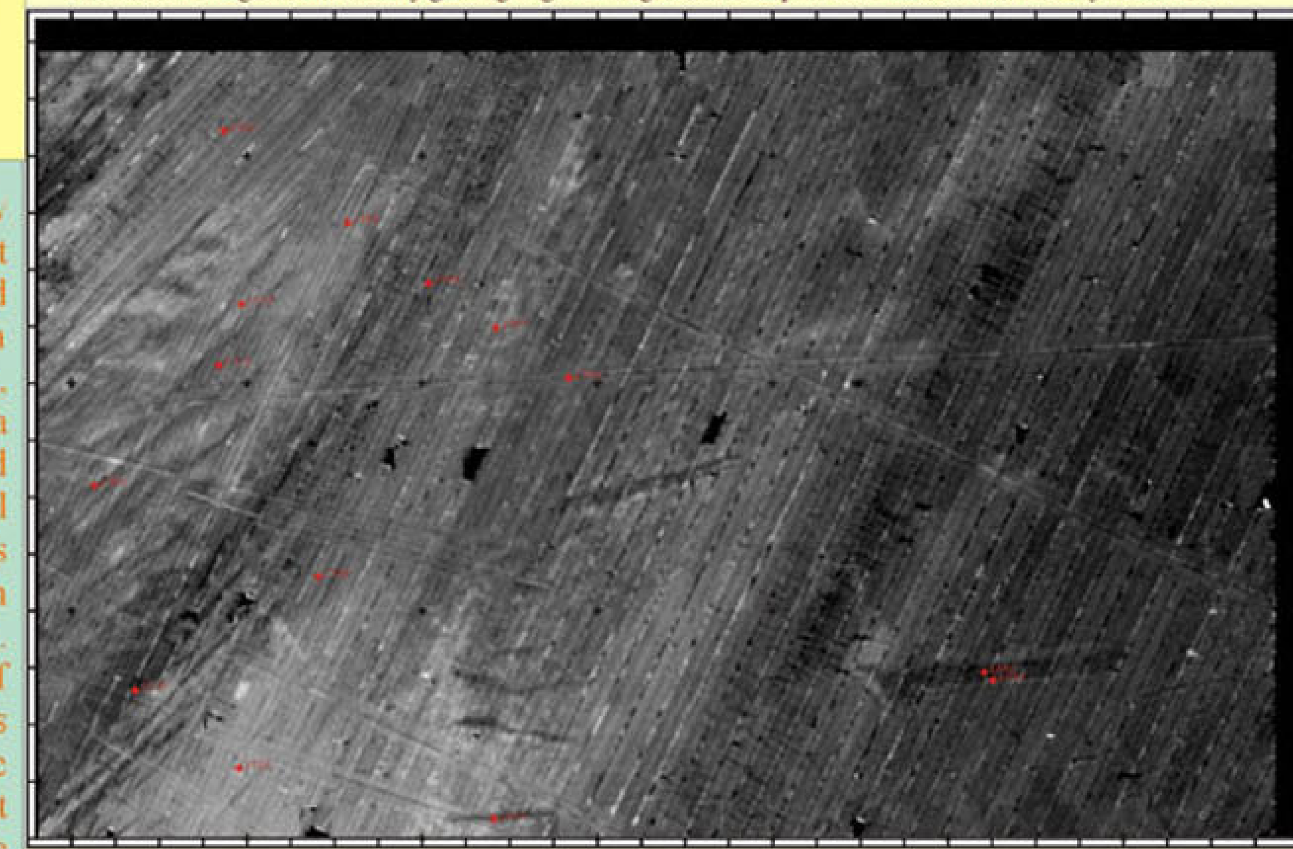
The grazing angle is computed from two vectors (incident angle and surface normal)

Taking into account the local topographic variations of the seabed, the estimated grazing angle for each beam has been computed from available adjacent soundings with a adjusted radius using a least squares fit with a Butterworth weighting function. The backscatter vs. grazing angle dependence for each cell was computed by averaging backscatter data by the corresponding grazing angles using all data with the same grazing angle from different survey lines.

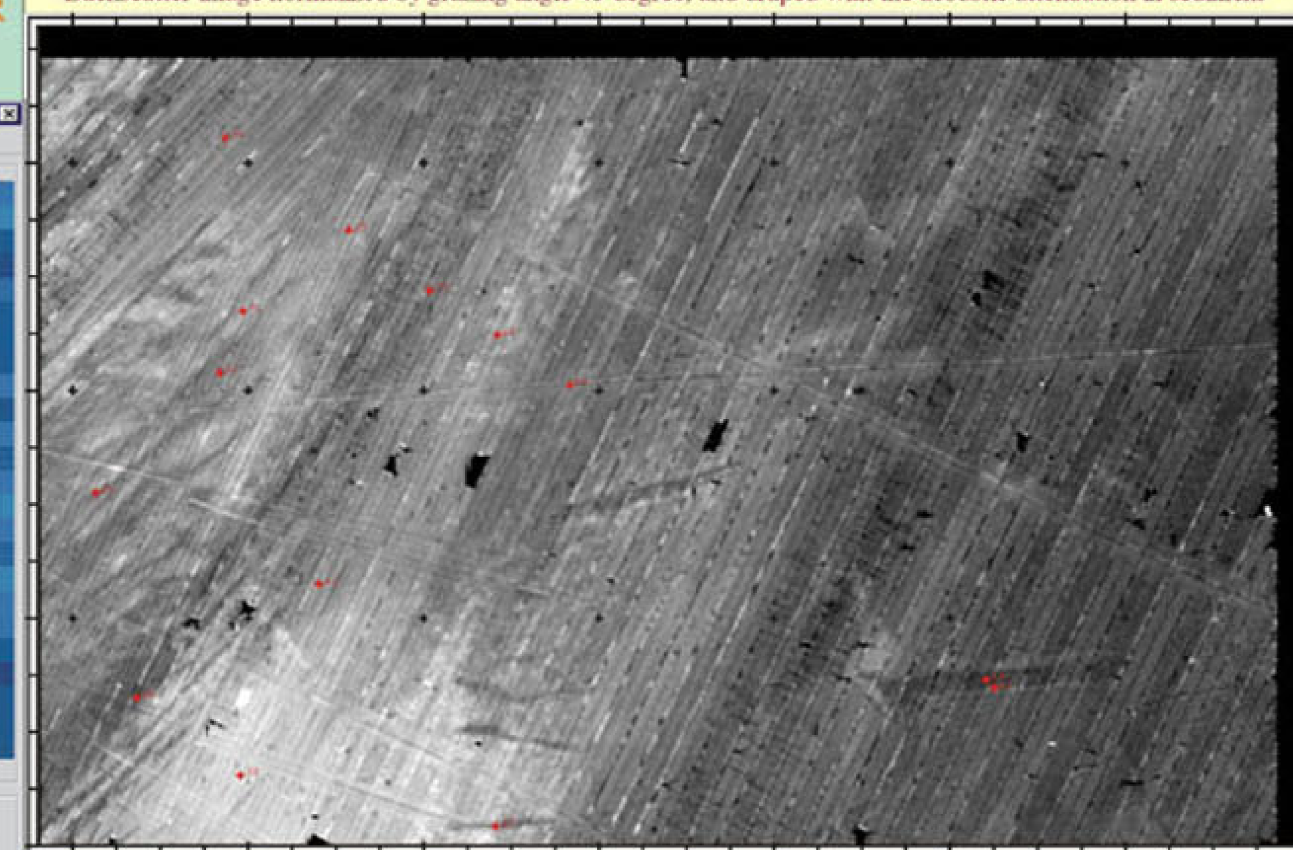
An unsupervised K-means clustering algorithm was implemented using backscatter strength vs. the best-estimated grazing angle as the elements in feature space. In this approach, the geometric distance between the object and the corresponding cluster- representative was computed as an element of the feature space at each iteration.

Image Normalization

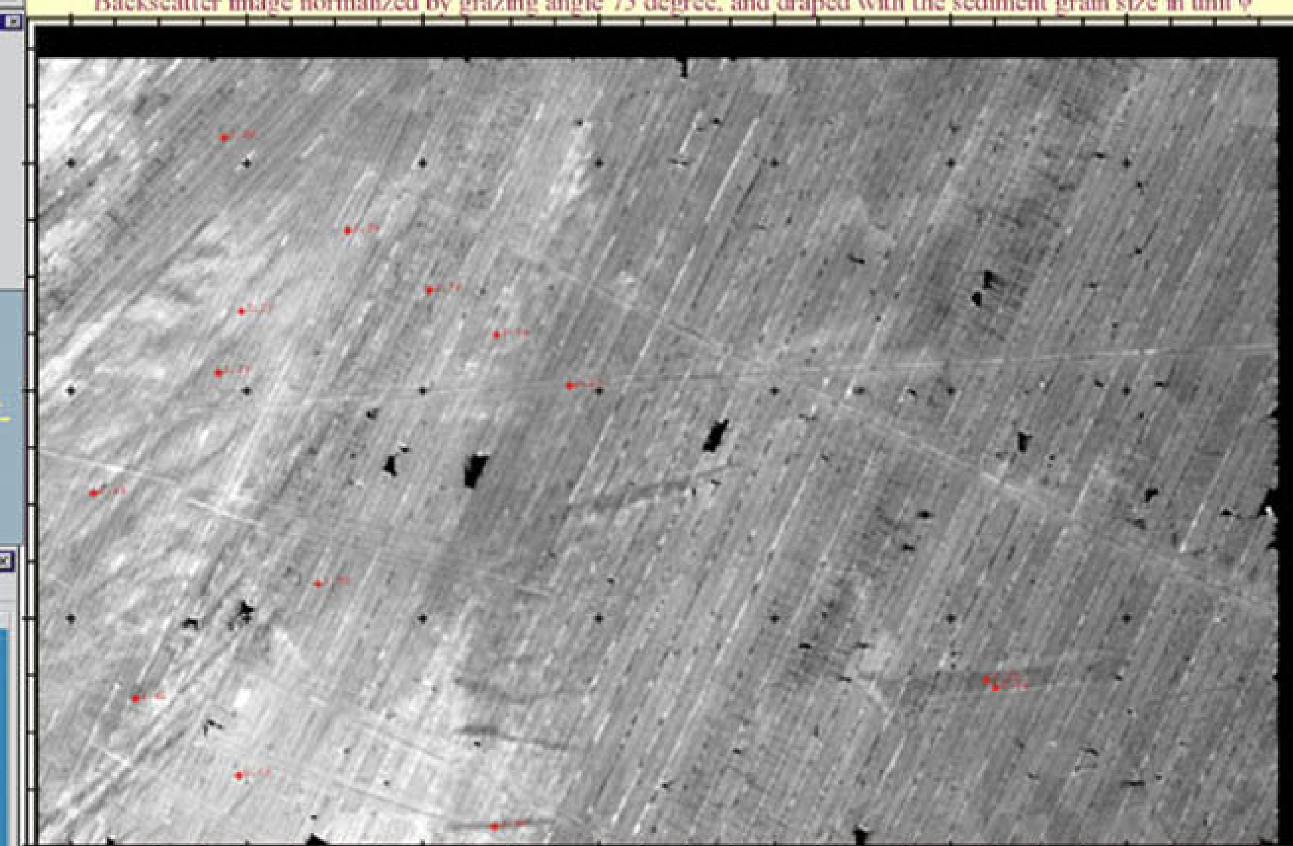
Backscatter image normalized by grazing angle 30 degree, and draped with the acoustic velocity in sediment



Backscatter image normalized by grazing angle 45 degree, and draped with the acoustic attenuation in sediment



Backscatter image normalized by grazing angle 75 degree, and draped with the sediment grain size in unit ϕ

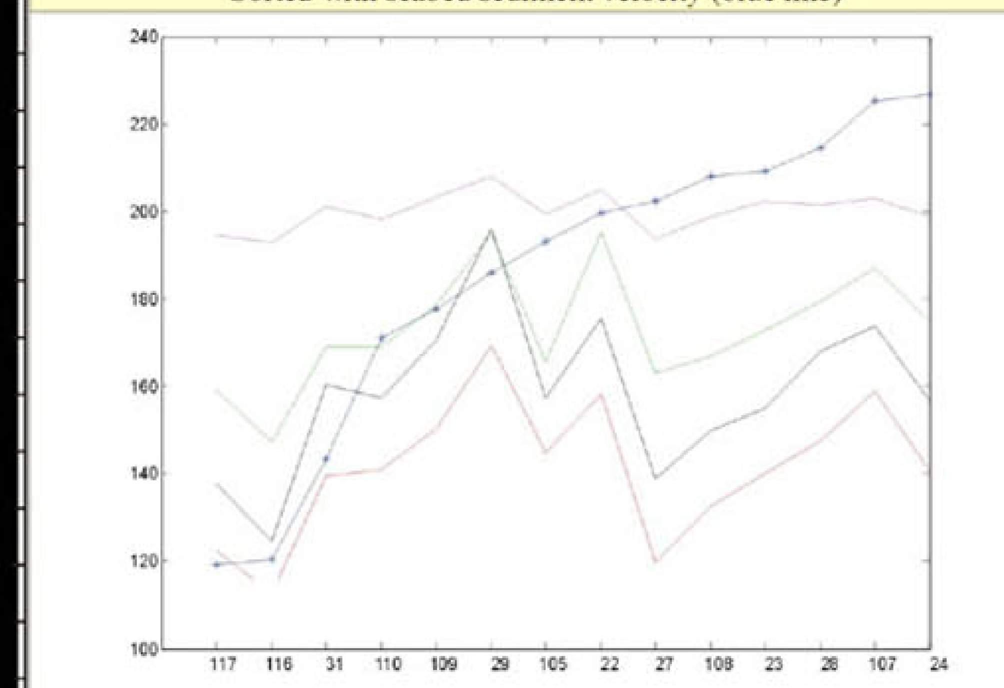


Backscatter image normalization by different grazing angles produces different looking imagery both in terms of large scale signal levels and fine scale seabed features. This may provide an opportunity to re-evaluate ground truth data and to get a better understanding of the relationship between backscatter and seafloor properties.

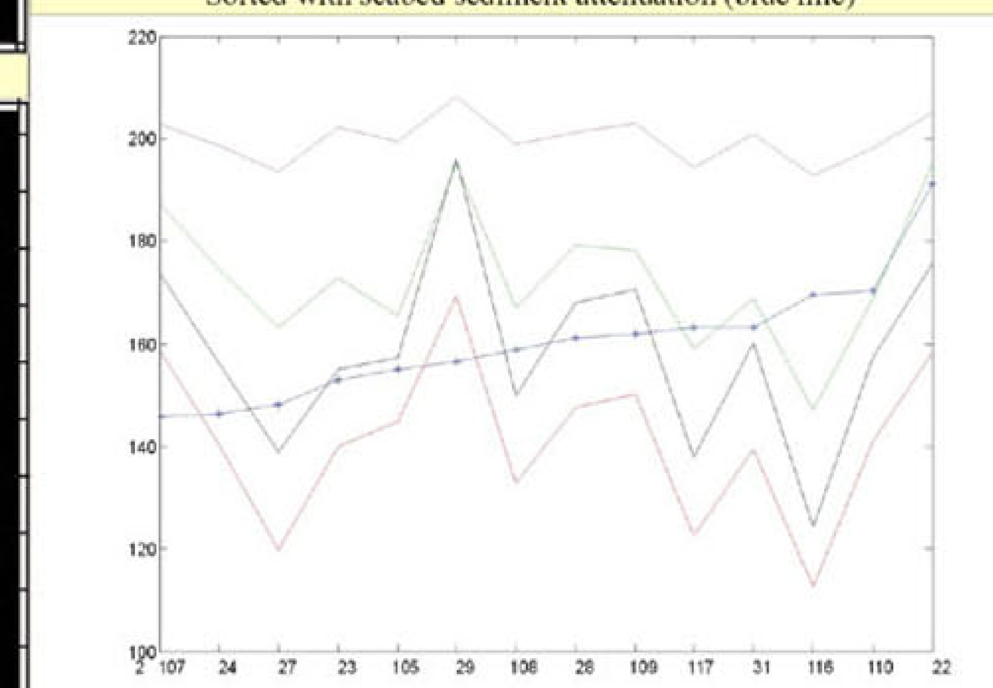
Conclusion

[a] With the proposed algorithm for the grazing angle computation, using all available bathymetric data, the local topographic effects of backscatter can be removed. [b] Backscatter data normalized by the grazing angle will change the image appearance, which may improve the correlation with the ground truth data. [c] After removing the topographic effect, the grain size is thought to be a principal determinant of backscatter intensity, since the grain size affects both surface roughness and volumetric heterogeneity.

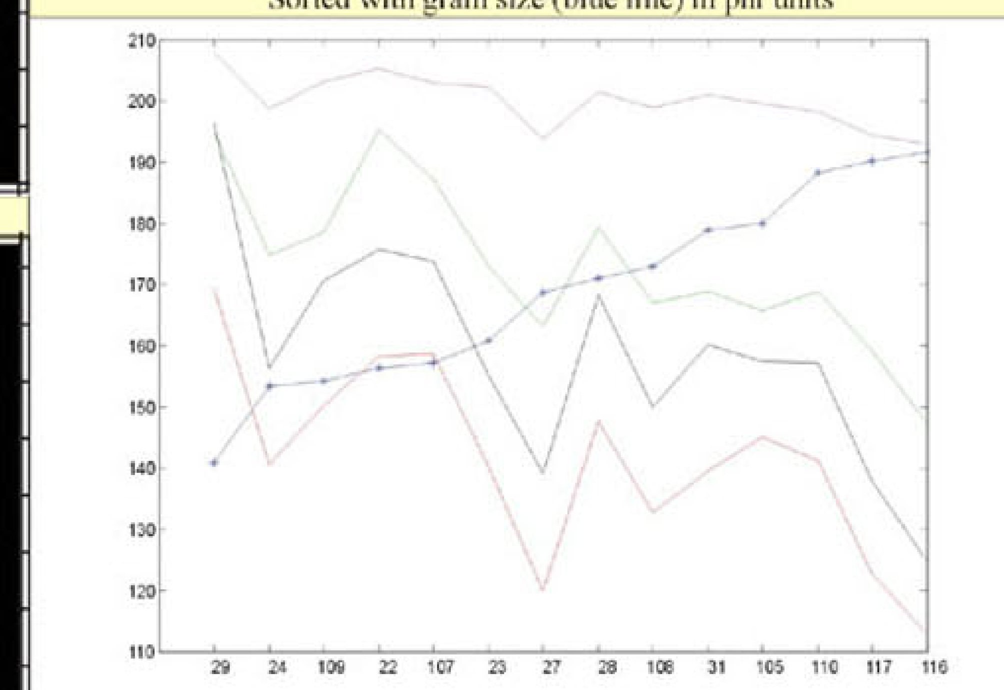
Sorted with seabed sediment velocity (blue line)



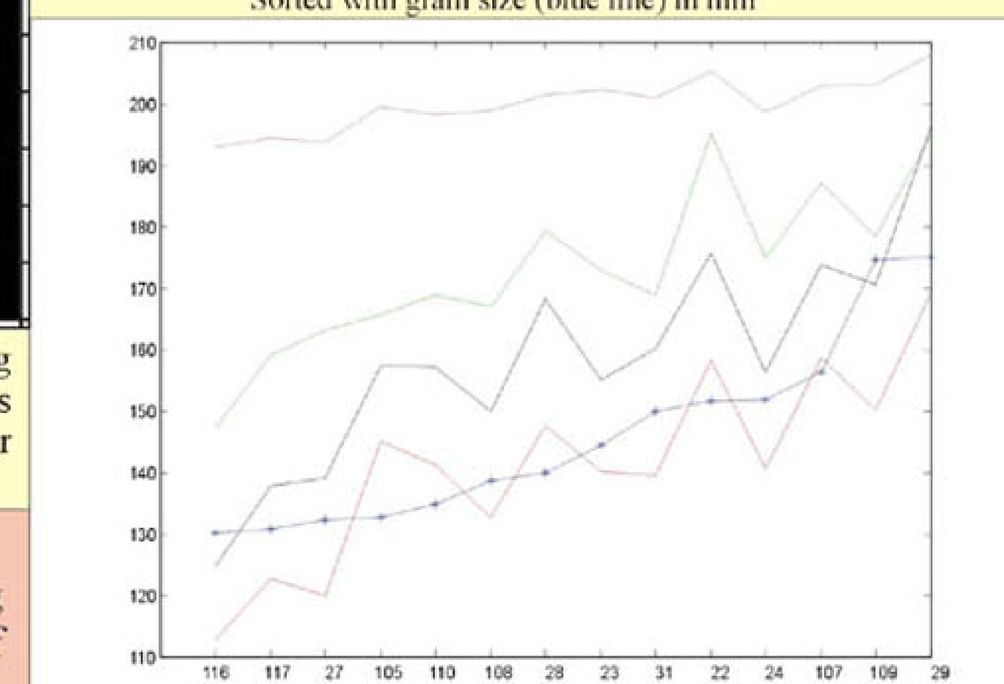
Sorted with seabed sediment attenuation (blue line)



Sorted with grain size (blue line) in phi units



Sorted with grain size (blue line) in mm



Sorted ground truth data (blue star line) with the corresponding backscatter values from normalized image by estimated grazing angle of 30 degree (red), 45 degree (black), 75 degree (green), and from non-normalized data (magenta). Grain size in both Phi units and millimeters shows a better correlation than with non-normalized backscatter data.