Washington State Mapping Workshop:

Modern Sonar

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Underwater

Sea water is favorable to the propagation of acoustic waves but there are many limitations:

- Attenuation due to absorption
- Slow propagation speed (1500 m/s vs 300000 km/s for radar)
- Perturbations of propagation by variations in sound speed
- Deformation of the signals transmitted
- Ambient Noise (environment and self-noise)

Variations in the marine environment play a very complex role in the transmission of acoustic signals.

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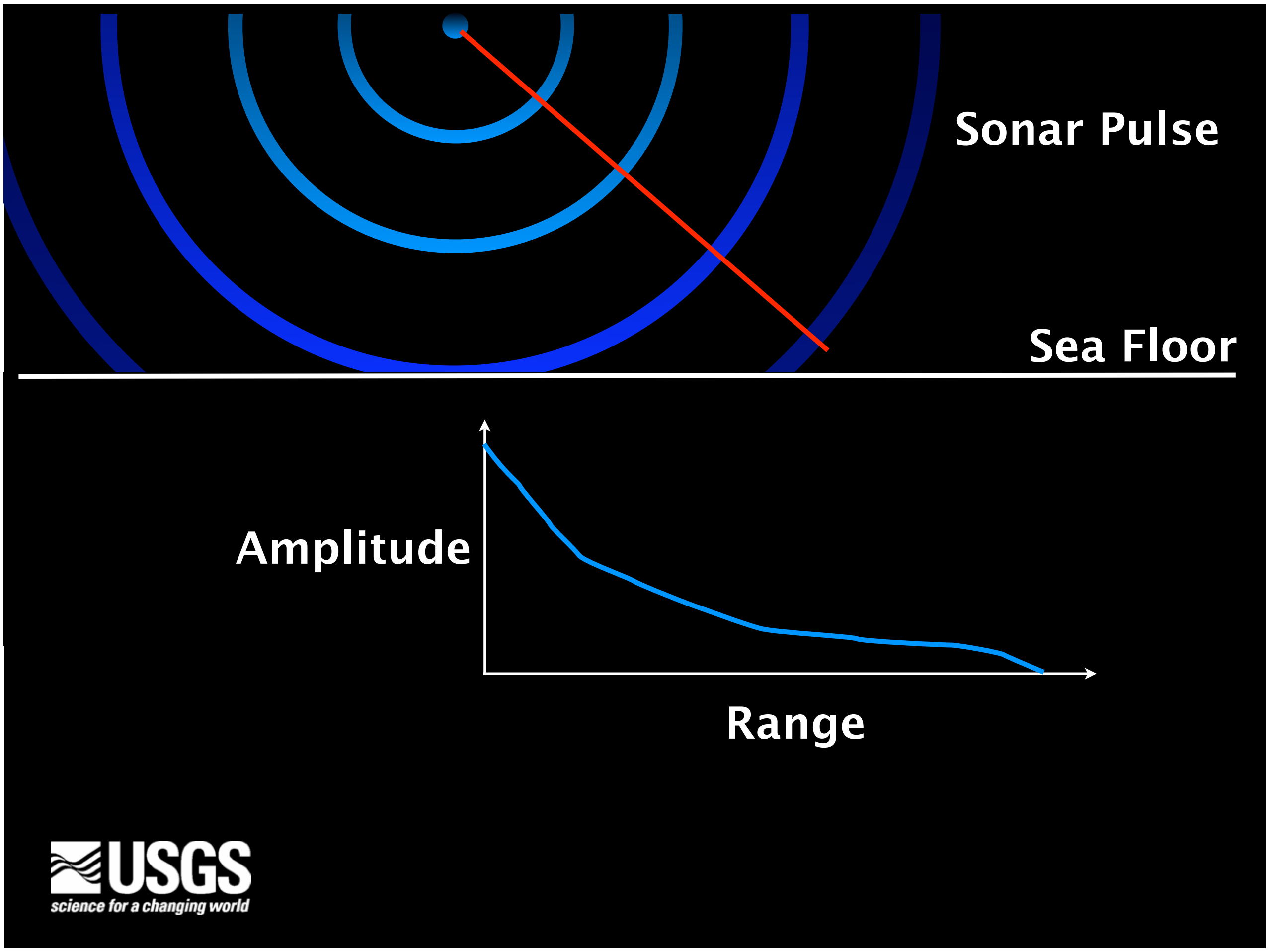

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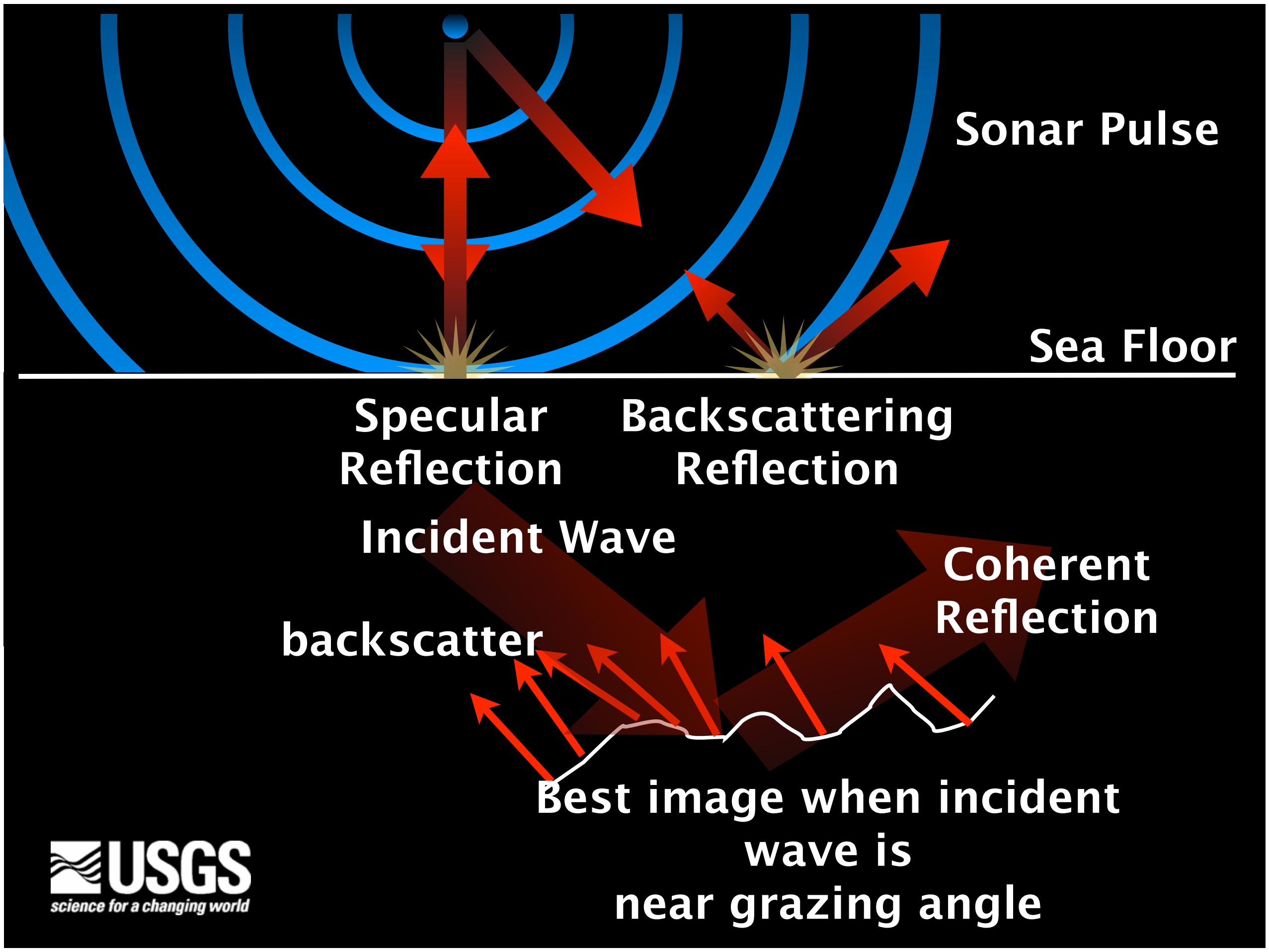
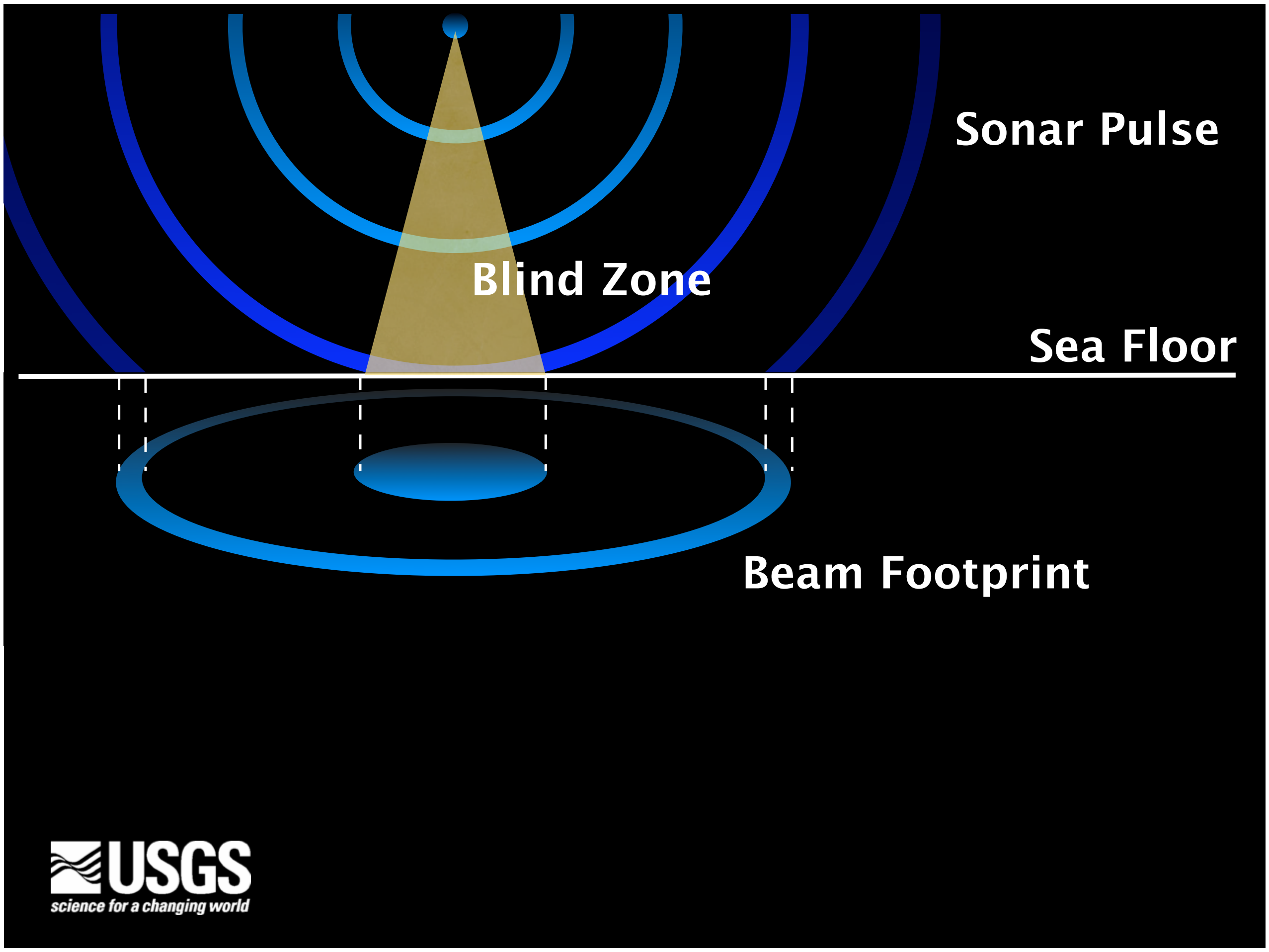
Example of spherical spreading. Amplitude decreases with range as the power in the wave front spreads out spherically.

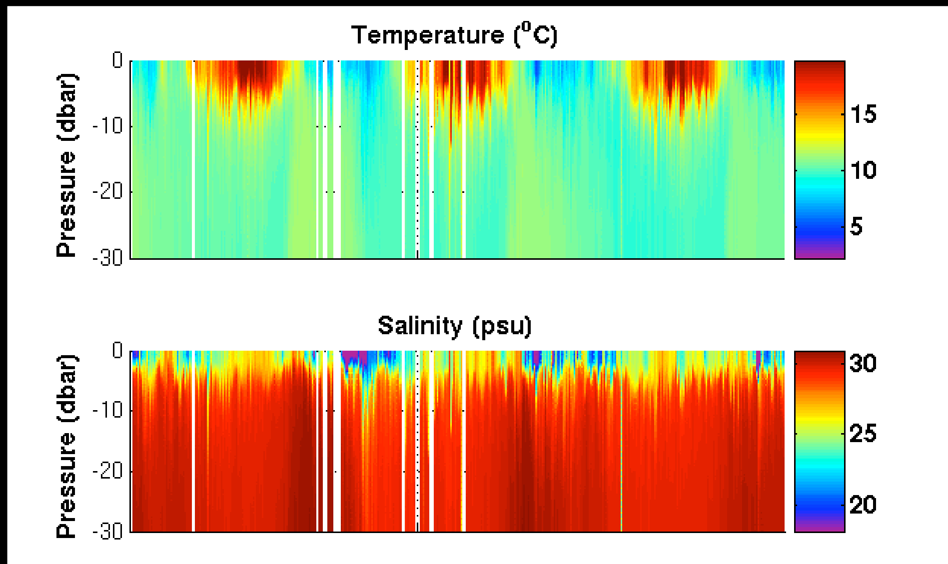


Ground reflections can be divided into two types: specular and backscatter. The detailed cartoon shows that backscattering is a complicated interaction between a rough surface and the acoustic wave. The strength of the backscattering echo is a function of grazing angle and surface roughness.



Sonar beam pattern changes with range. Initially, the spherical wave hits the bed over a broad circular area (defined by the pulse width), as the wave front propagates outward, the beam footprint becomes increasingly narrow.

Hood Canal ORCA Bouy Data (January 21, 2007)



http://orca.ocean.washington.edu/data_twanoh.html

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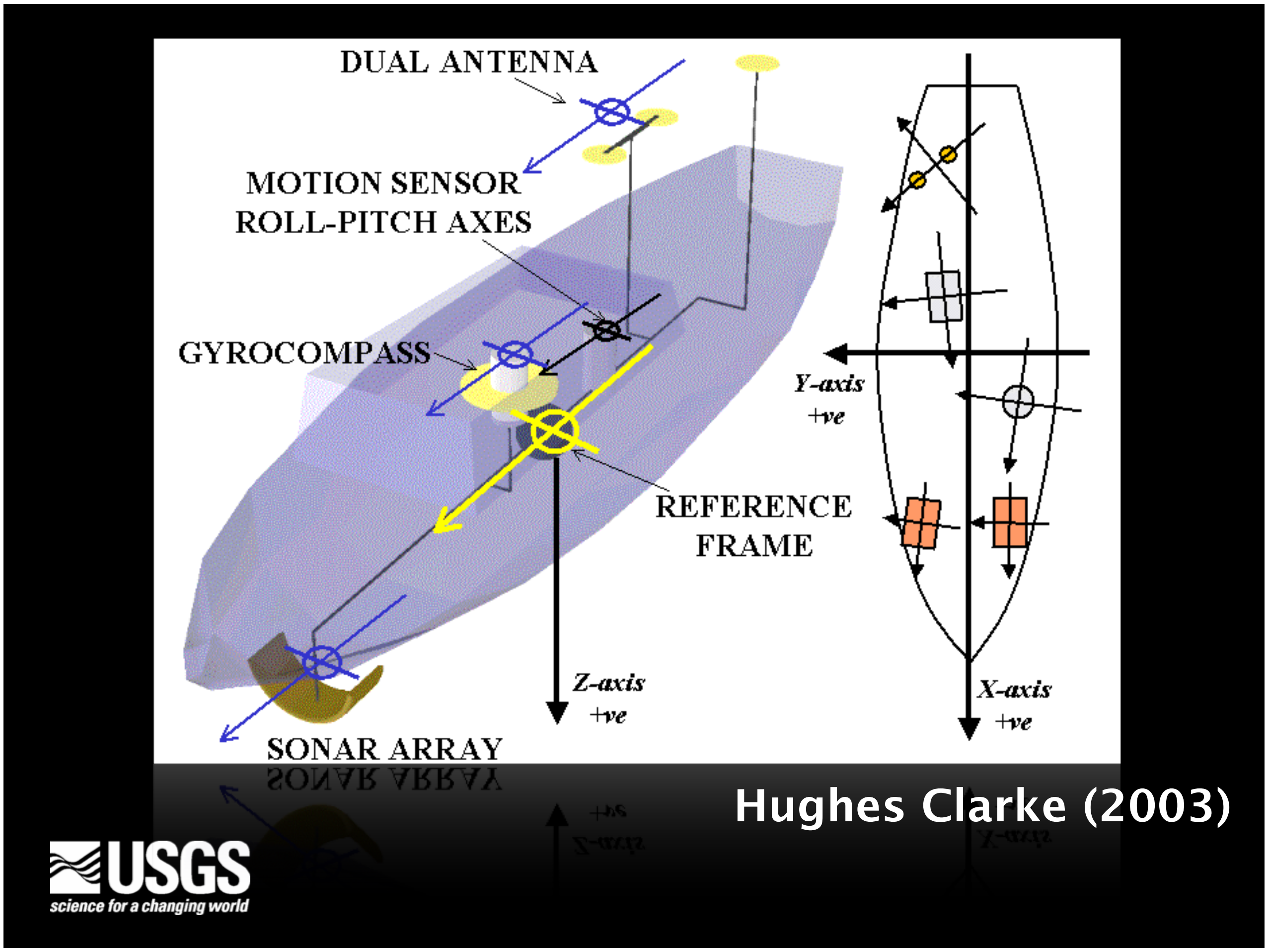
Sound velocity in the ocean is complicated. Uncertainty in the propagation of sound through the water column is one of the largest sources of error in modern surveying.



Modern survey vessels must coordinate the static and dynamic measurements of GPS, inertial reference units, gyrocompasses and the sonar system to exacting tolerances while underway at Sea. Latency in the communication networks, problems in time synchronization, and data throughput capacities are first-order controls on survey accuracy.

Mapping Sonars

Three basic classes of mapping sonar:

- Single-Beam
  - inexpensive, insensitive to ocean conditions
  - Poor resolution
- Sidescan Sonar
  - moderate expense, wide swath, best-possible imagery
  - poor navigation, no bathymetry
- Multibeam
  - best-possible bathymetry, imagery is improving
  - Expensive, narrow swath compared to sidescan

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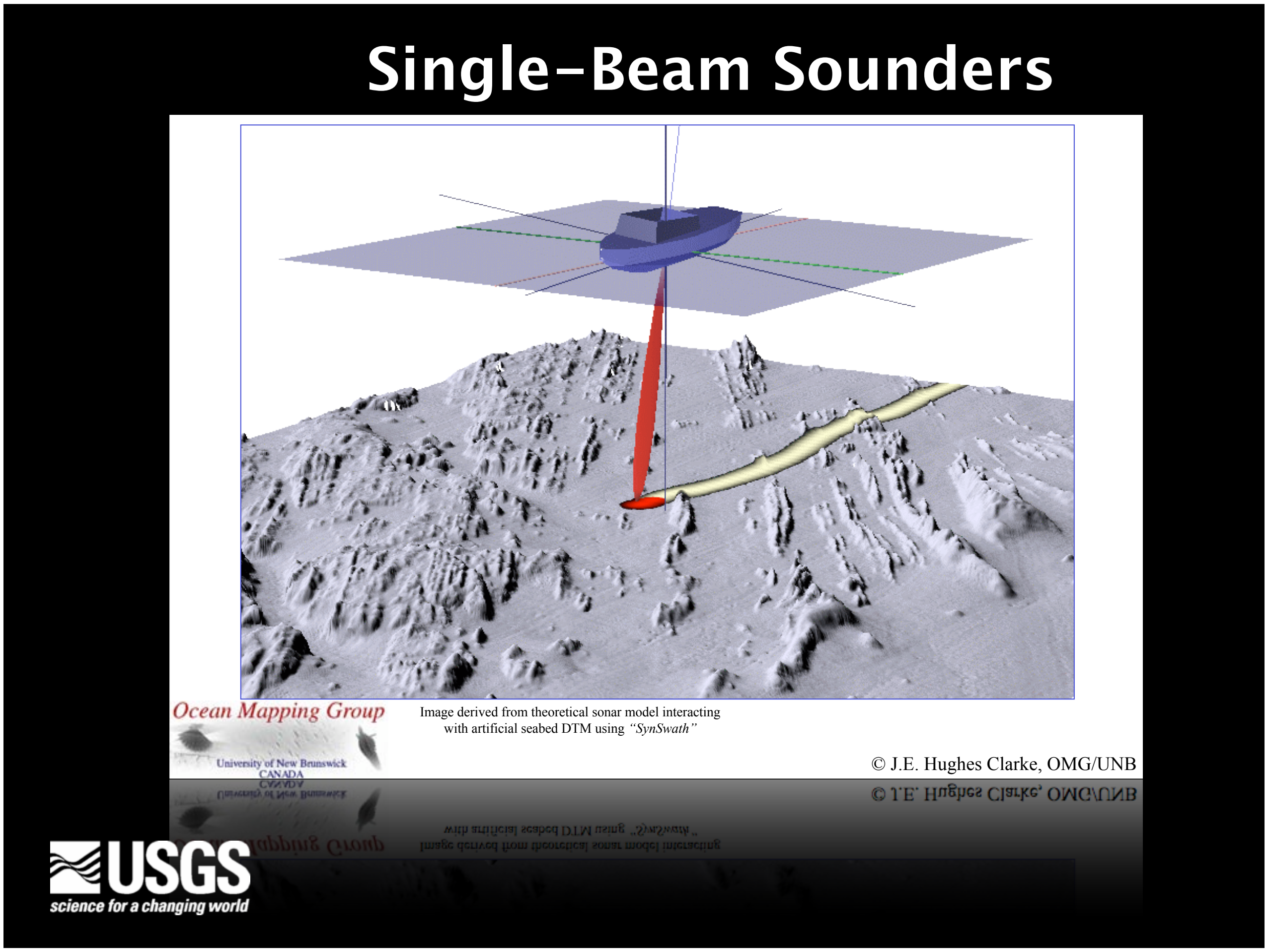

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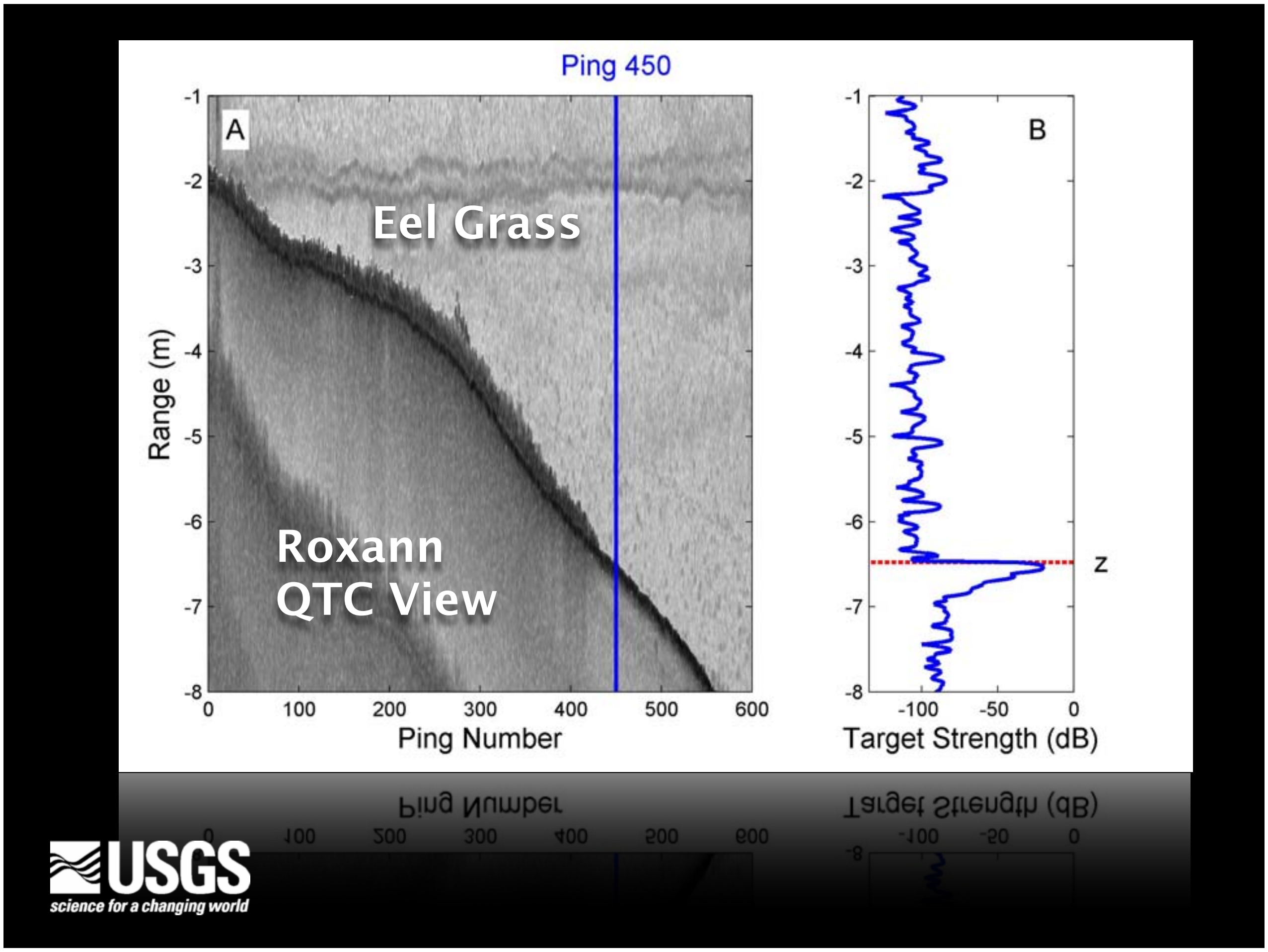
Single-beam sonar systems are a valid and traditional approach to sea floor mapping. Though ubiquitous, reliable and easy to deploy, these systems are limited by their design to low-resolution mapping applications. Most of the sea floor remains uncharted in typical survey designs.



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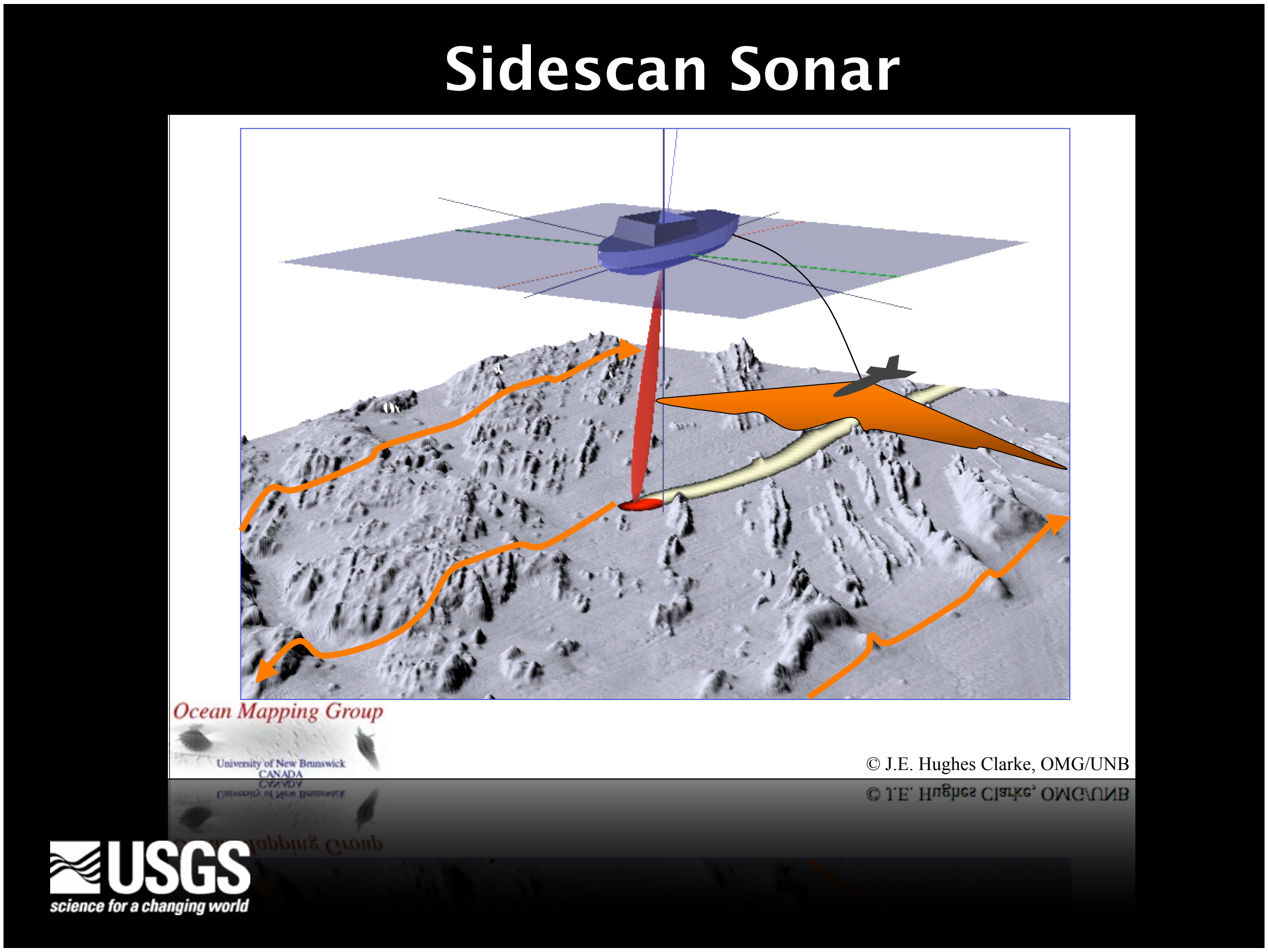
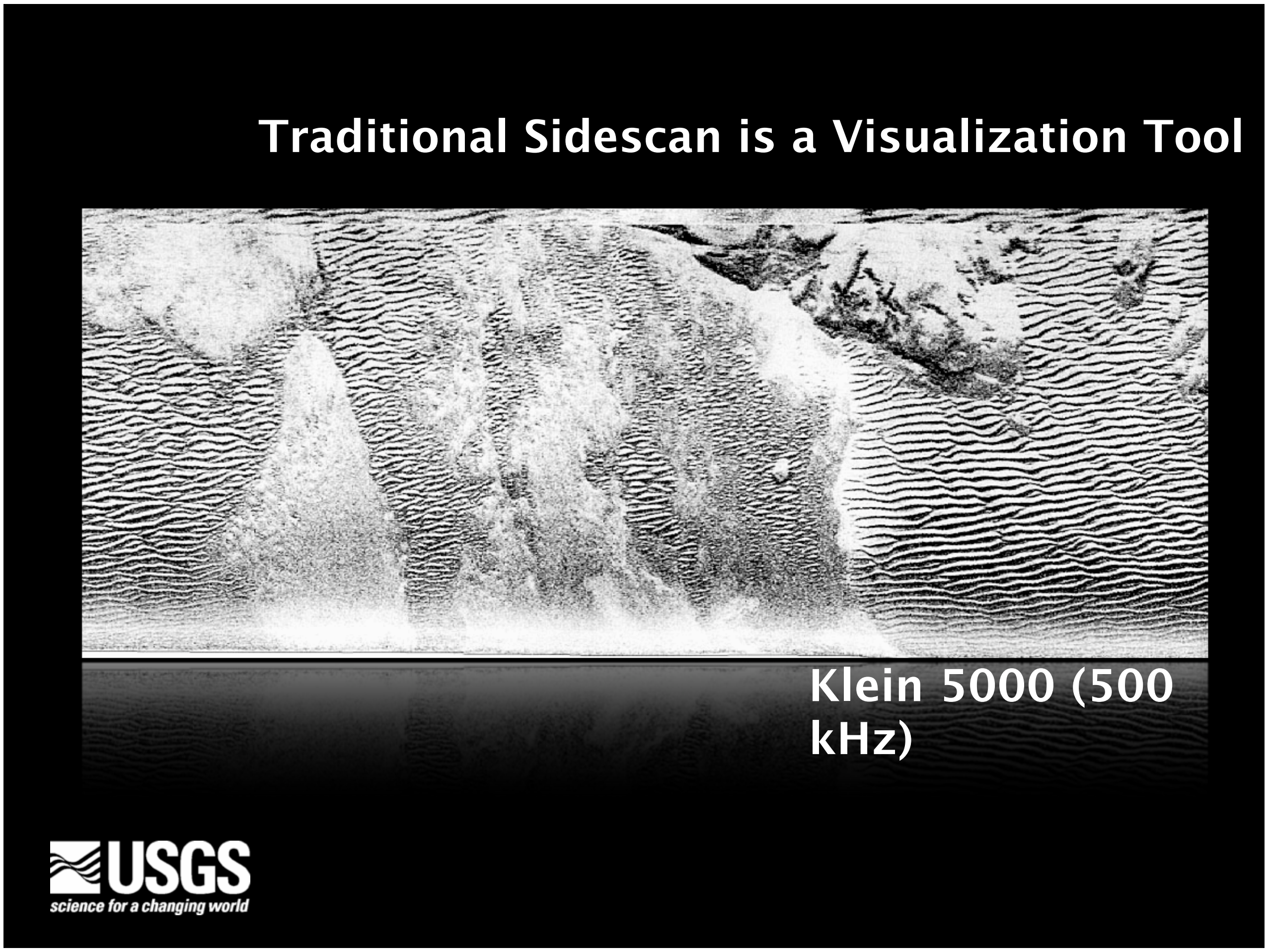
Example of a single-beam sonar profile along a track line. The sea floor is indicated by the dark amplitude line dipping steeply offshore. Multiple lines will be needed to make a surface. The fuzzy section between ping 0 and ping 400 is sea grass. Interesting density gradients in the water column (about 2 m depth) are visible. Single-beam data is not obsolete, but for mapping purposes, it is limited to 2-D profiles.



Sidescan sonar can provide very high-resolution sea floor imagery in a wide swath beneath the vessel. The wide swath is an advance over single-beam for mapping purposes, traditional sidescan is not designed for mapping elevations, only the imagery is available. Also, towed “fish” are difficult to precisely navigate, leading to problems geo-referencing the imagery.



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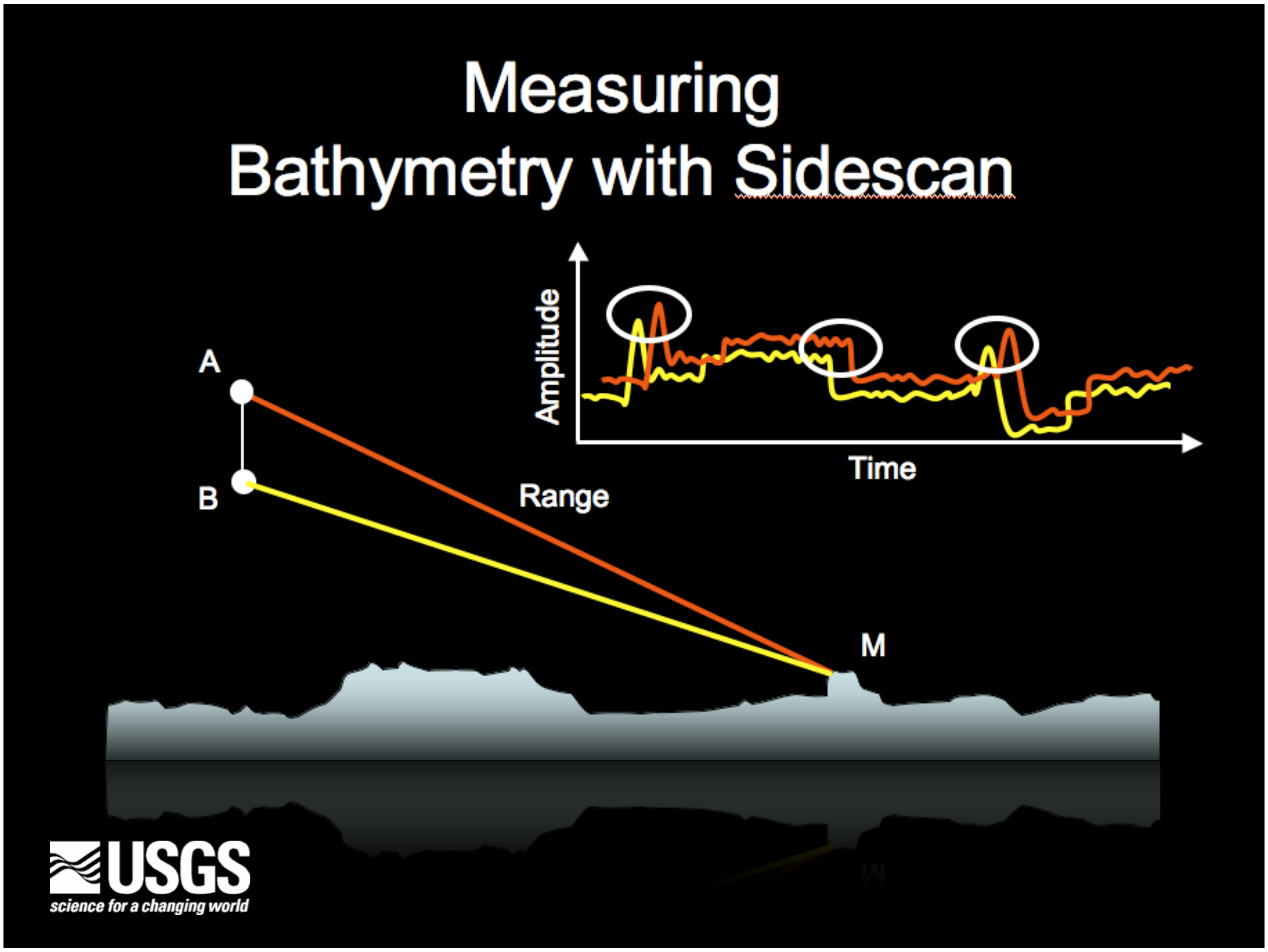
The photograph-like quality of high-resolution sidescan imagery is an important tool for interpreting sea floor characteristics. However, sidescan imagery is qualitative in nature, similar to a video tape of an aircraft flight.



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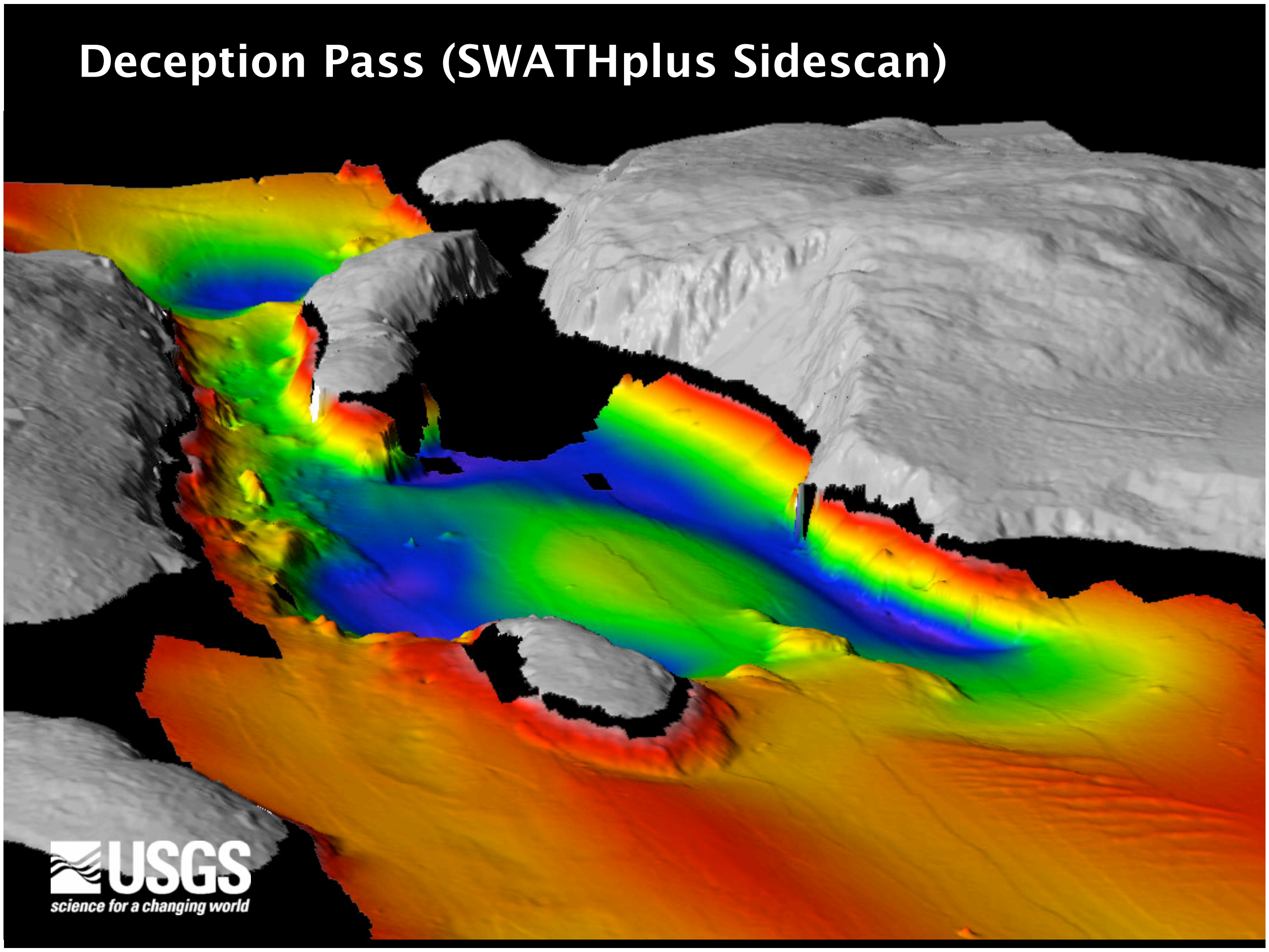
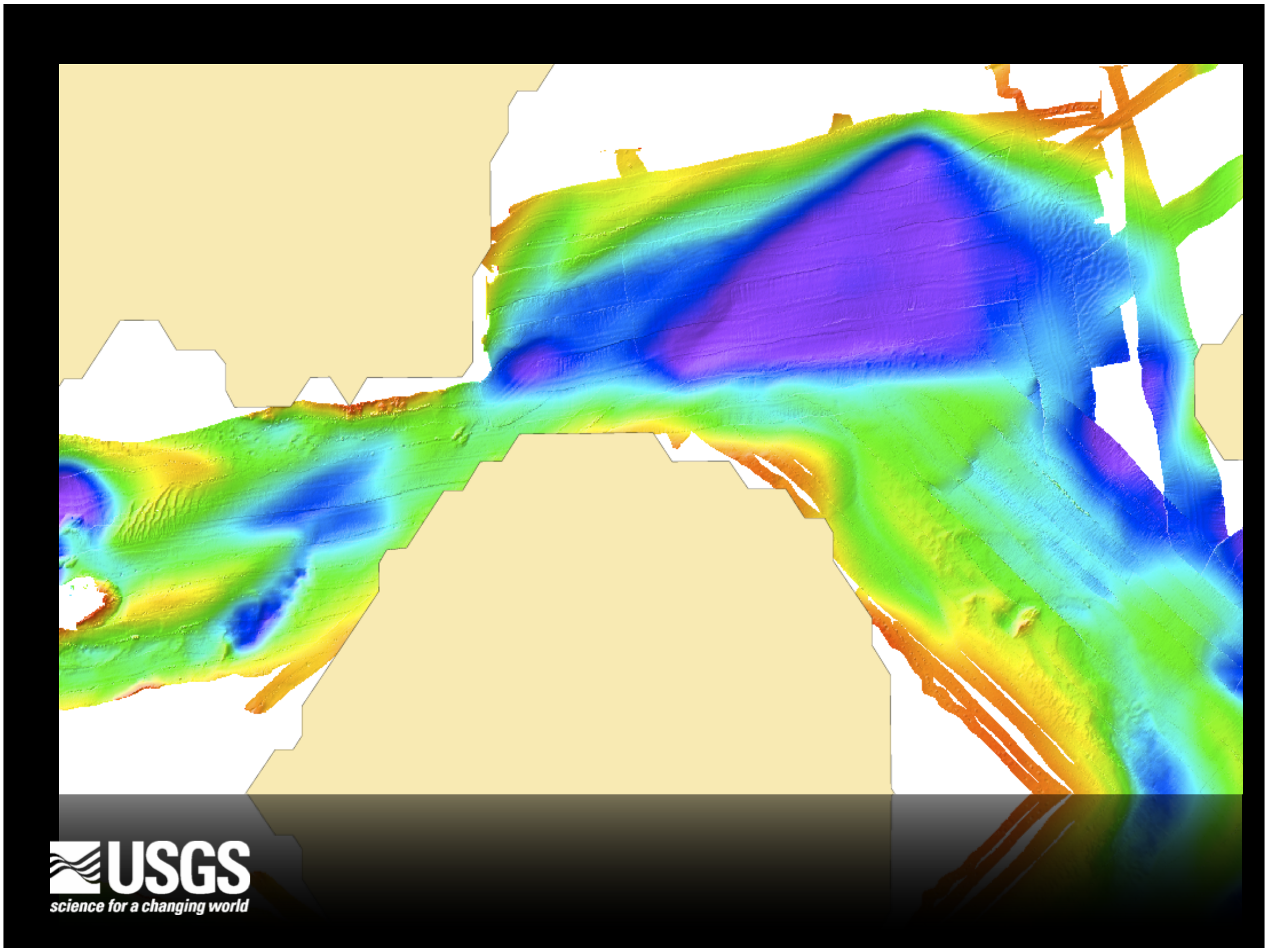
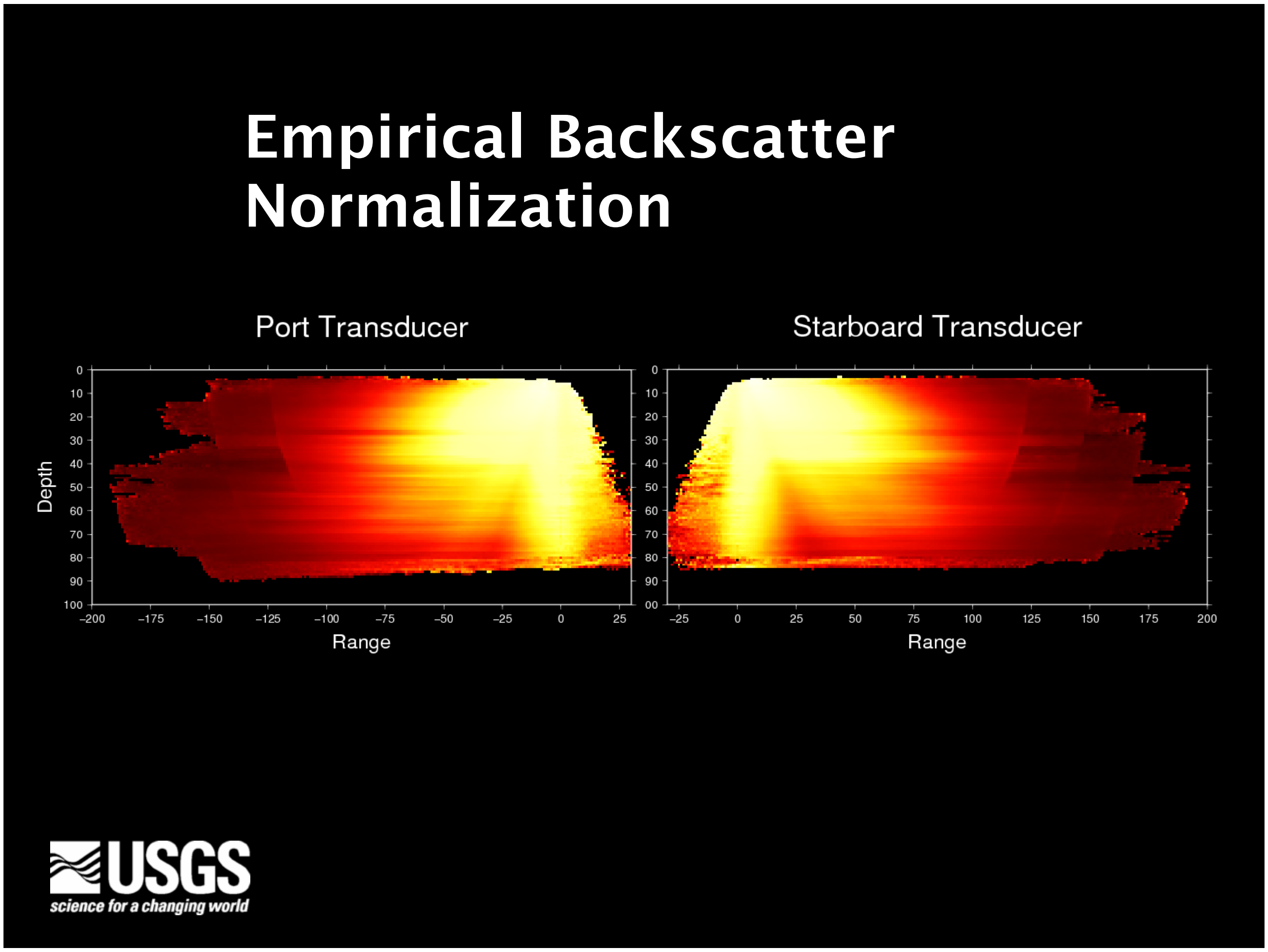
Bathymetric sidescan is an enhanced sidescan system utilizing multiple receive staves. The extra receive staves are used to measure the elevation angle to targets on the sea floor (hundreds per ping). This results in a true bathymetric map of the sea floor similar to multi-beam systems.



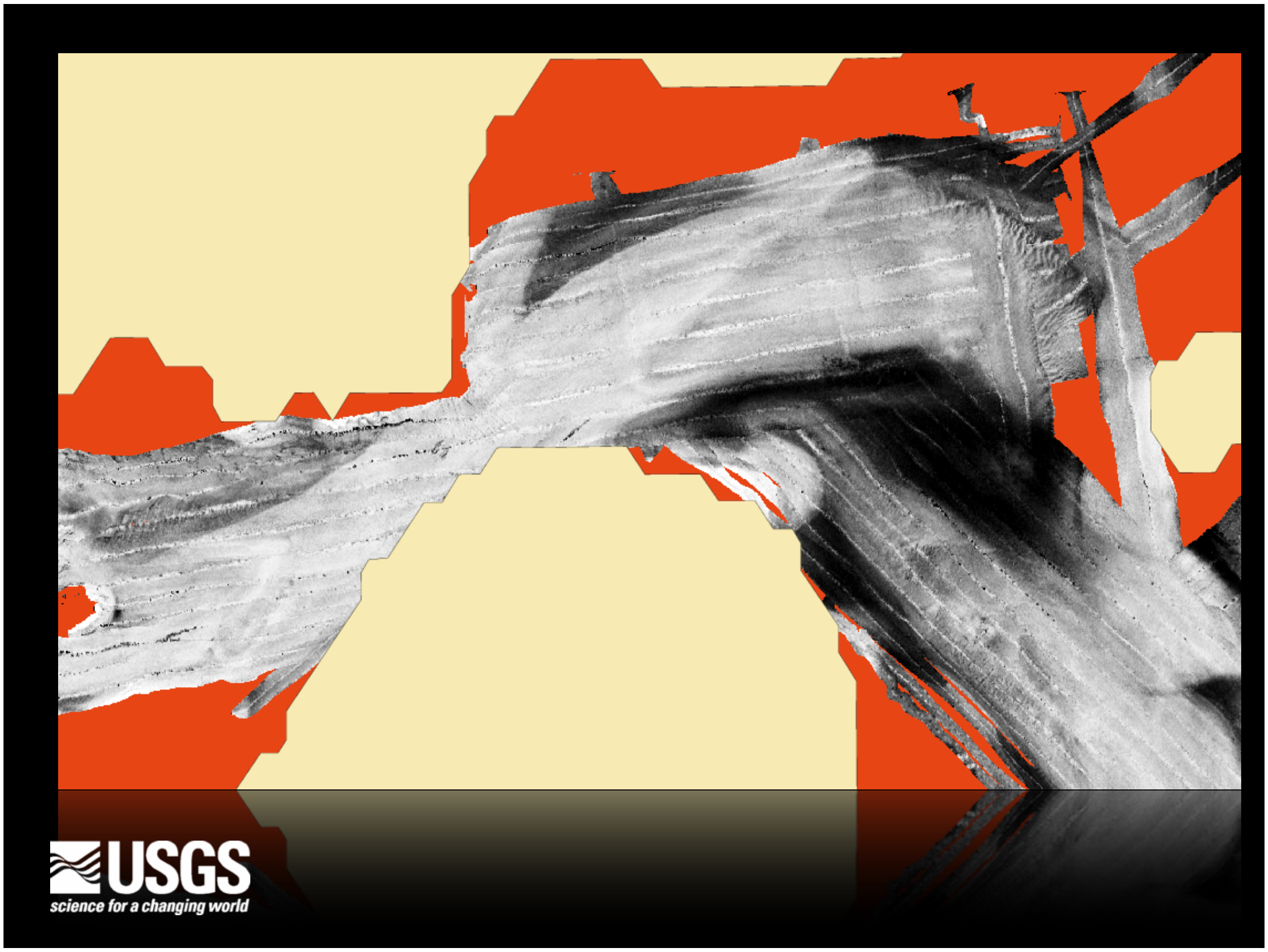
Example of bathymetric map of Deception Pass, Washington created with an SEA Inc. bathymetric sidescan system (234 kHz).



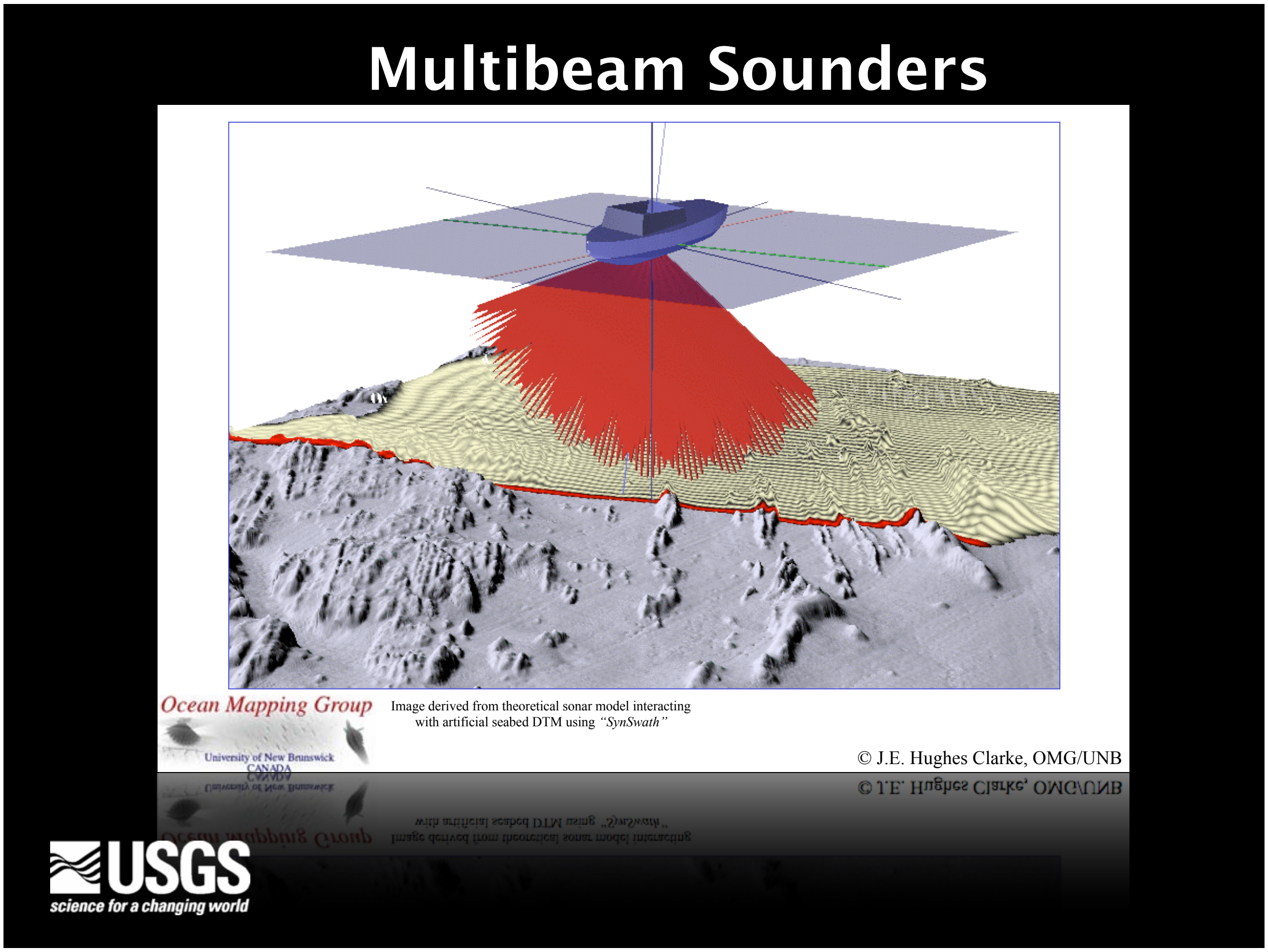
Plan-view of bathymetry of northern Skagit Bay, Washington collected with a bathymetric sidescan.



A cross-section map of the mean amplitude strength of the bathymetric sidescan system used by the USGS.



Map of the backscatter strength of Northern Skagit Bay. Light colors indicate stronger returns, dark colors indicate weak returns. The backscatter map is used to identify bottom type. In this case, strong returns are associated with course sand and gravels, while weak returns are associated with silt and mud.



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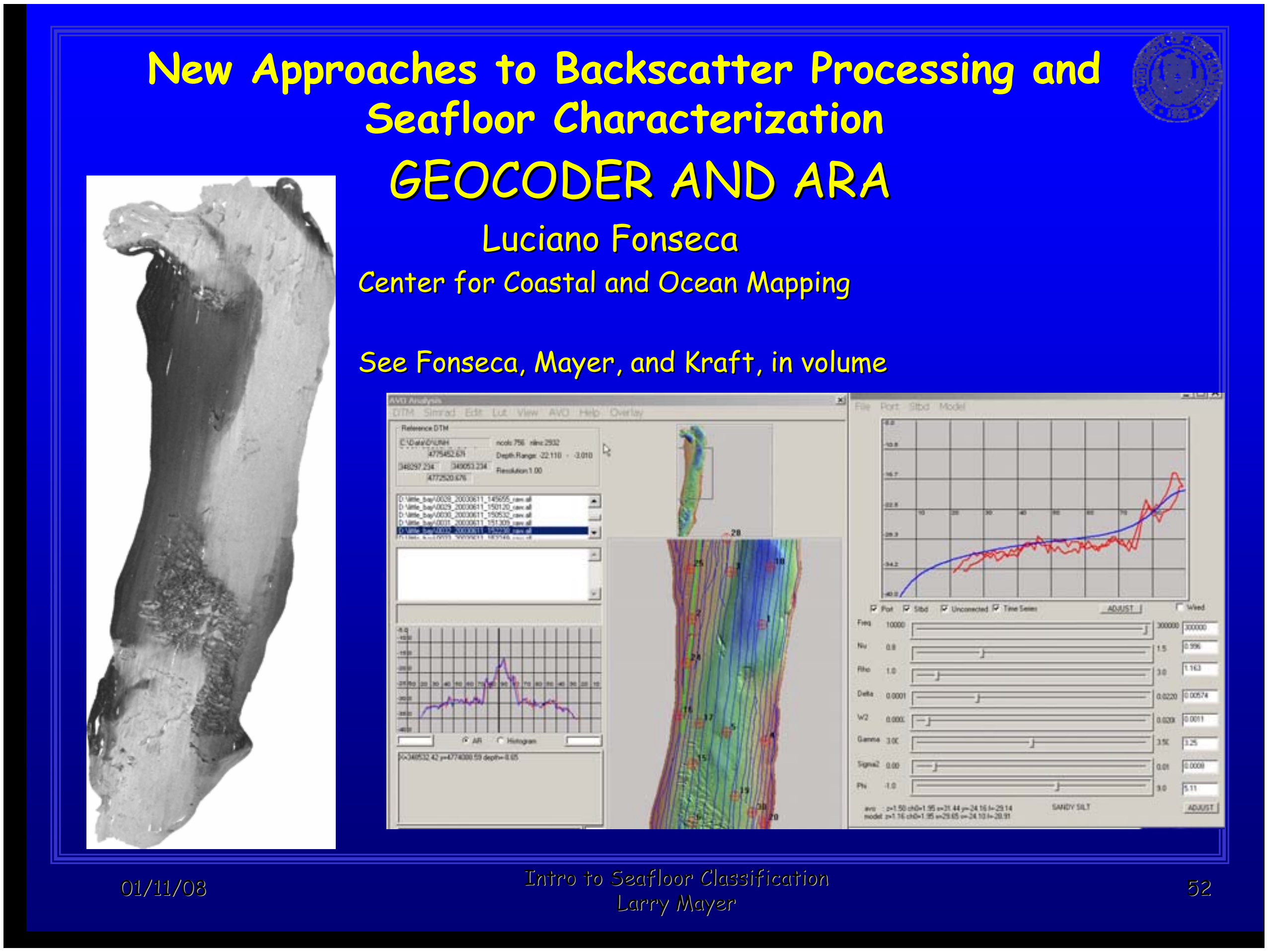
Multibeam sonar systems use sophisticated transducer arrays and high-speed signal processing to produce a large number of steered acoustic beams beneath the vessel. The most expensive and complicated of modern mapping systems, multibeams produce excellent, wide-swath bathymetry measurements.



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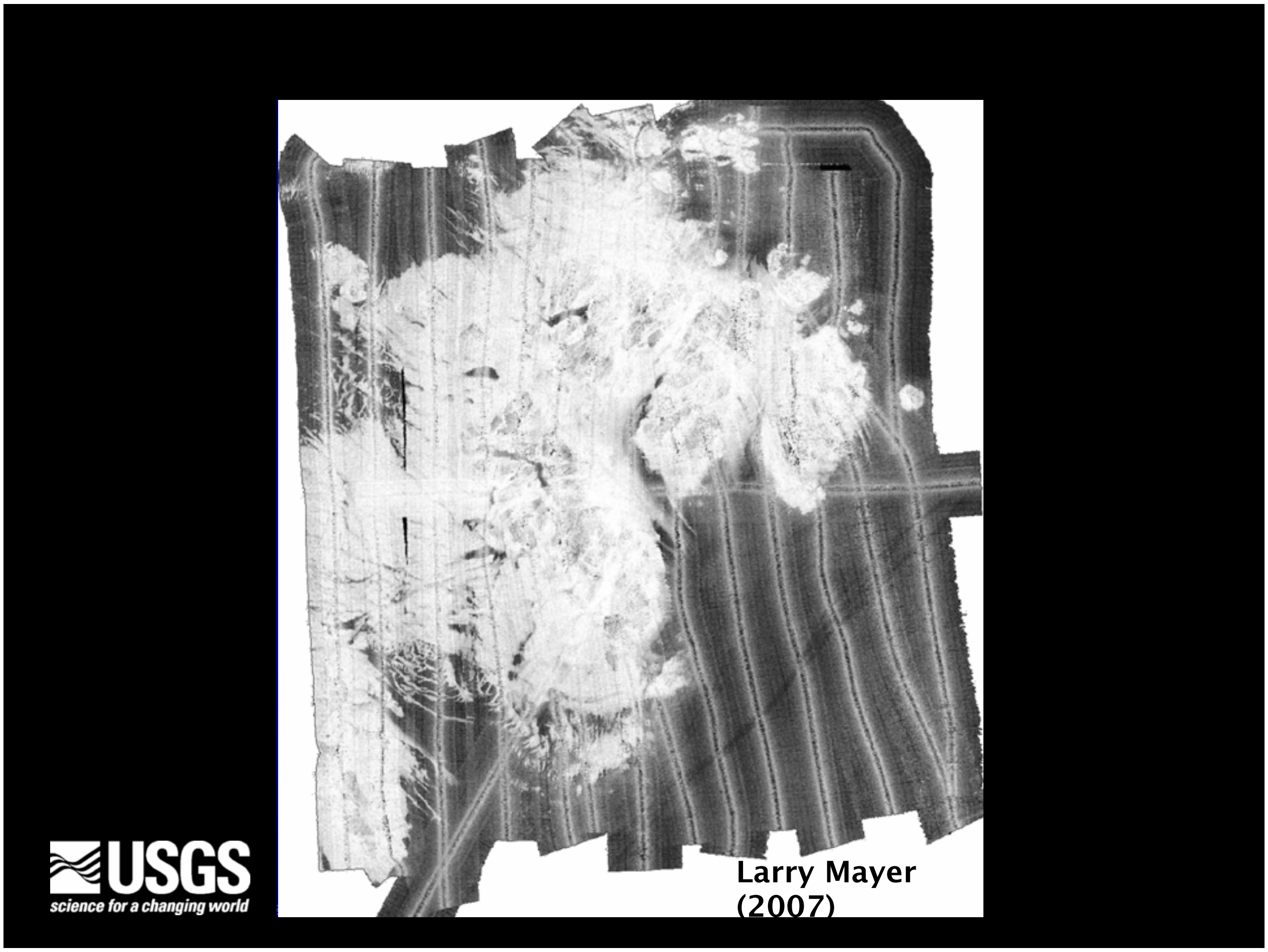
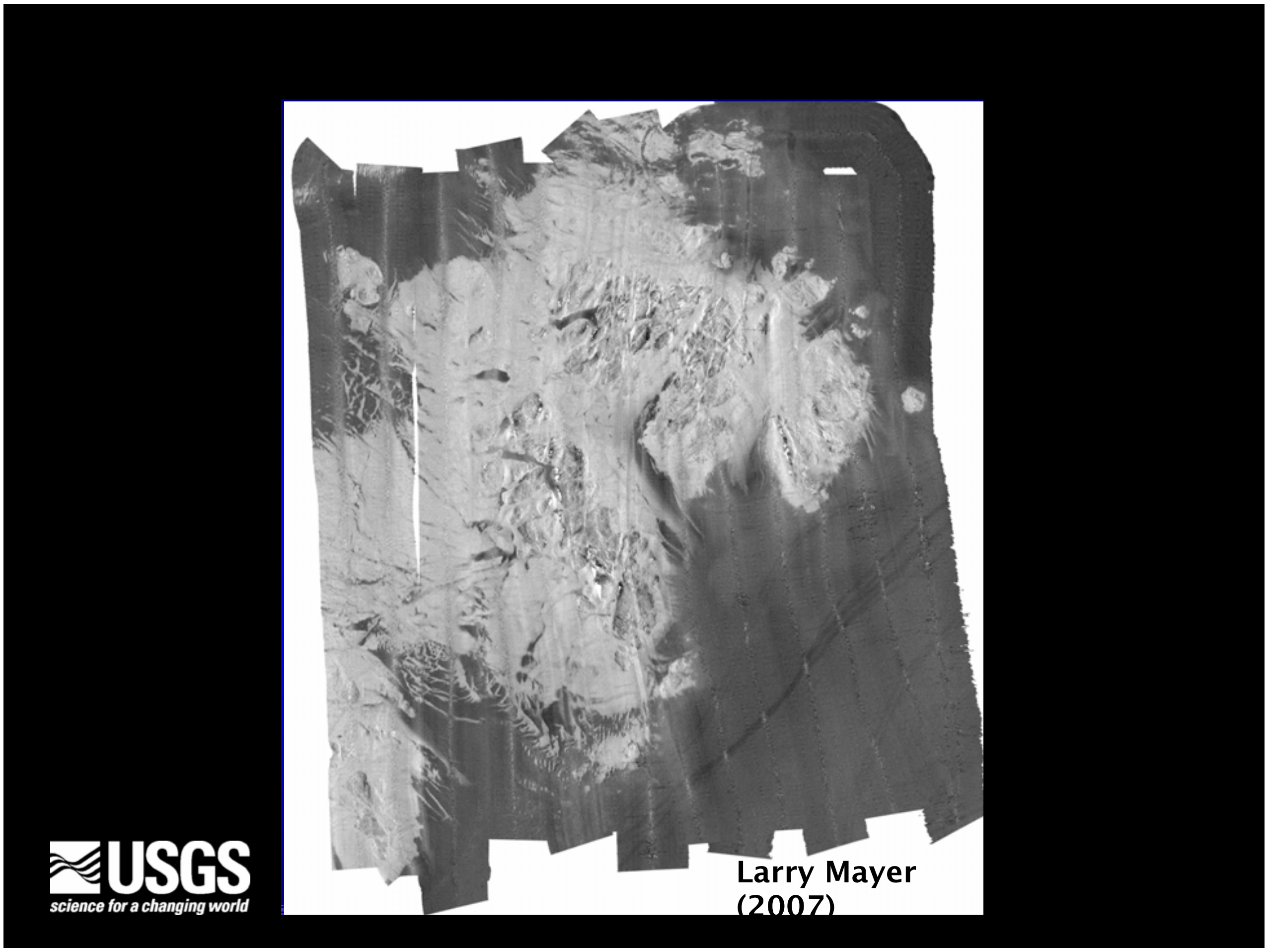
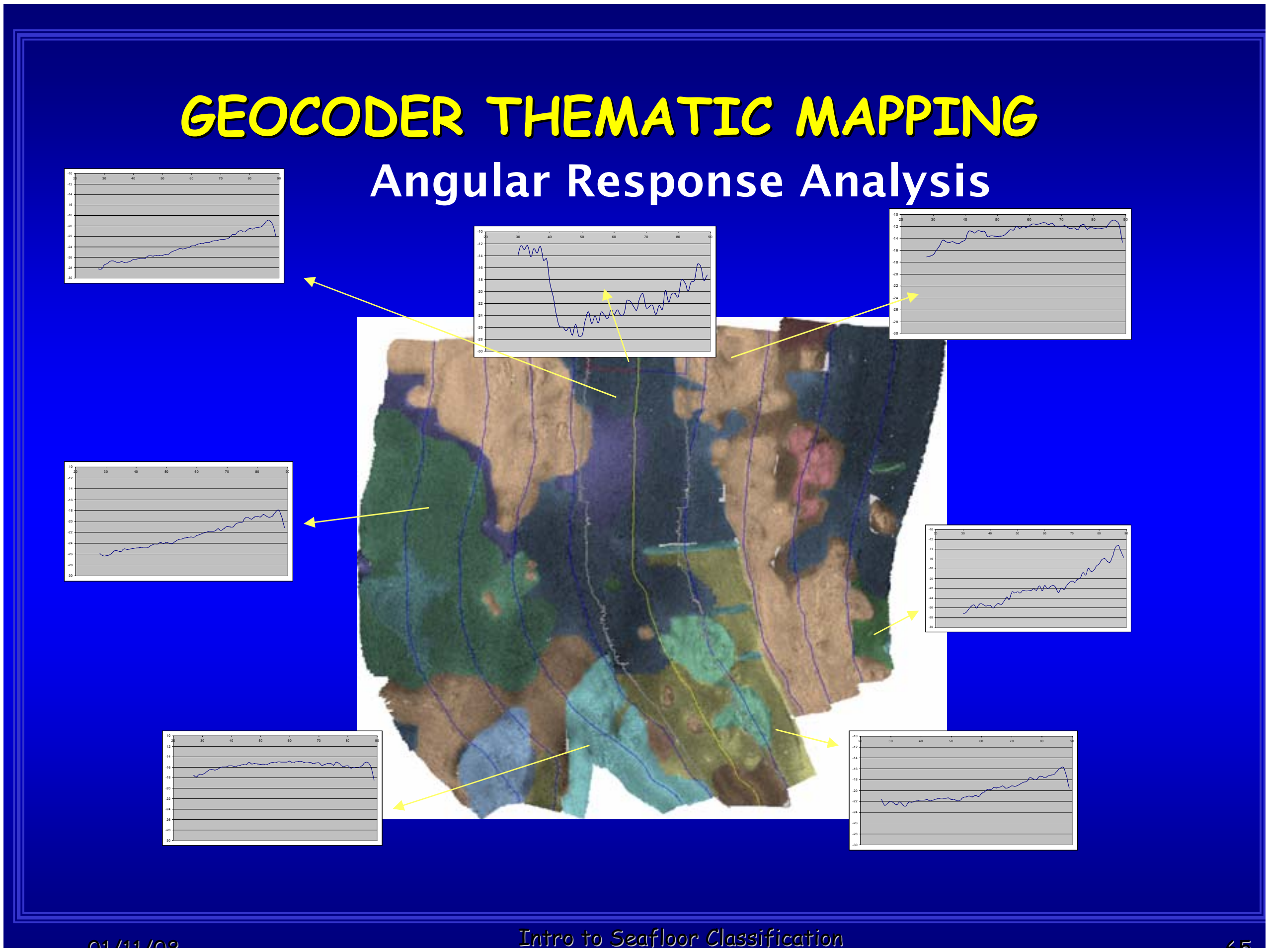
Poor acoustic imagery (compared to sidescan) has been a problem for multibeam systems. State-of-the-art tools such as Fonseca et al., Geocoder has dramatically improved the imagery. Furthermore, it attempts to go beyond imagery to sea bed classification.



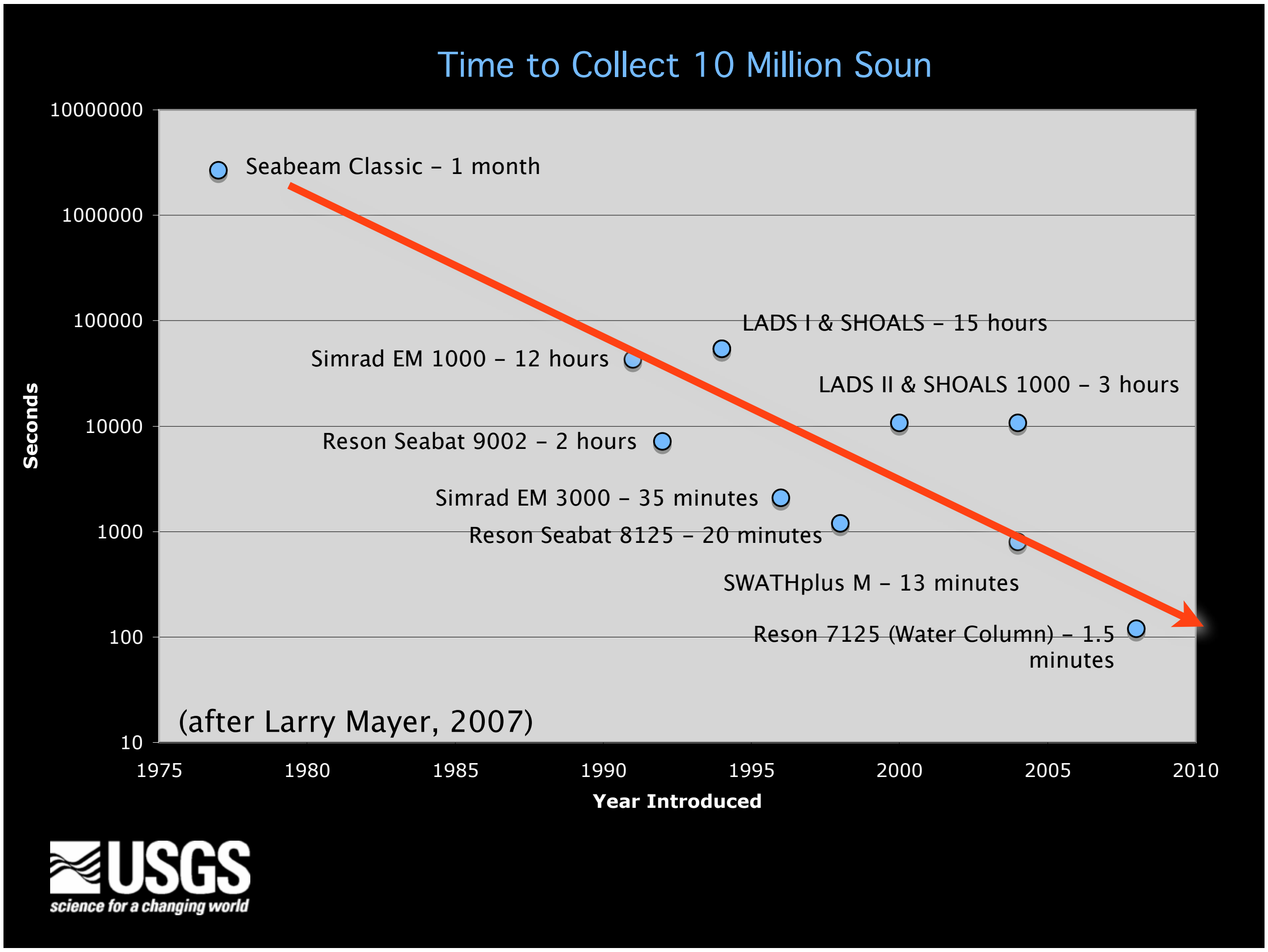
Before Geocoder, multibeam imagery was poor.



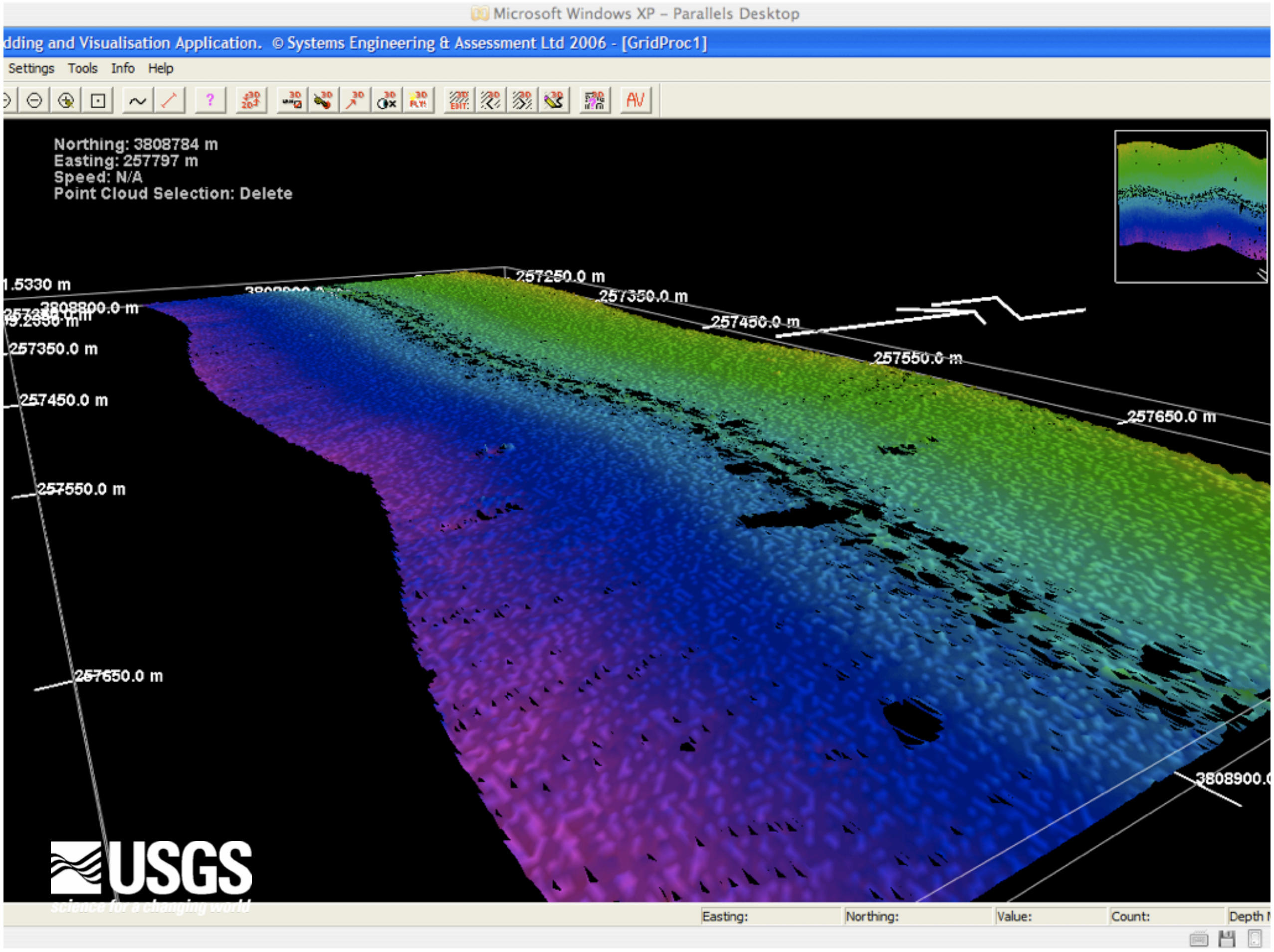
After Geocoder, the imagery is quite good.



The attenuation of acoustic signal strength with range is a function of the sea floor characteristics (backscattering property discussed earlier). The hypothesis is that each sea floor type (mud, silt, sand, etc) has a unique signature which can be used to classify the sea floor into habitat regions.



Sonar hardware has always collected data faster than humans can process it. Today, a Reson 7125 can collect 10 million soundings in less than 2 minutes. Automated computer processing is needed to process data at these rates.



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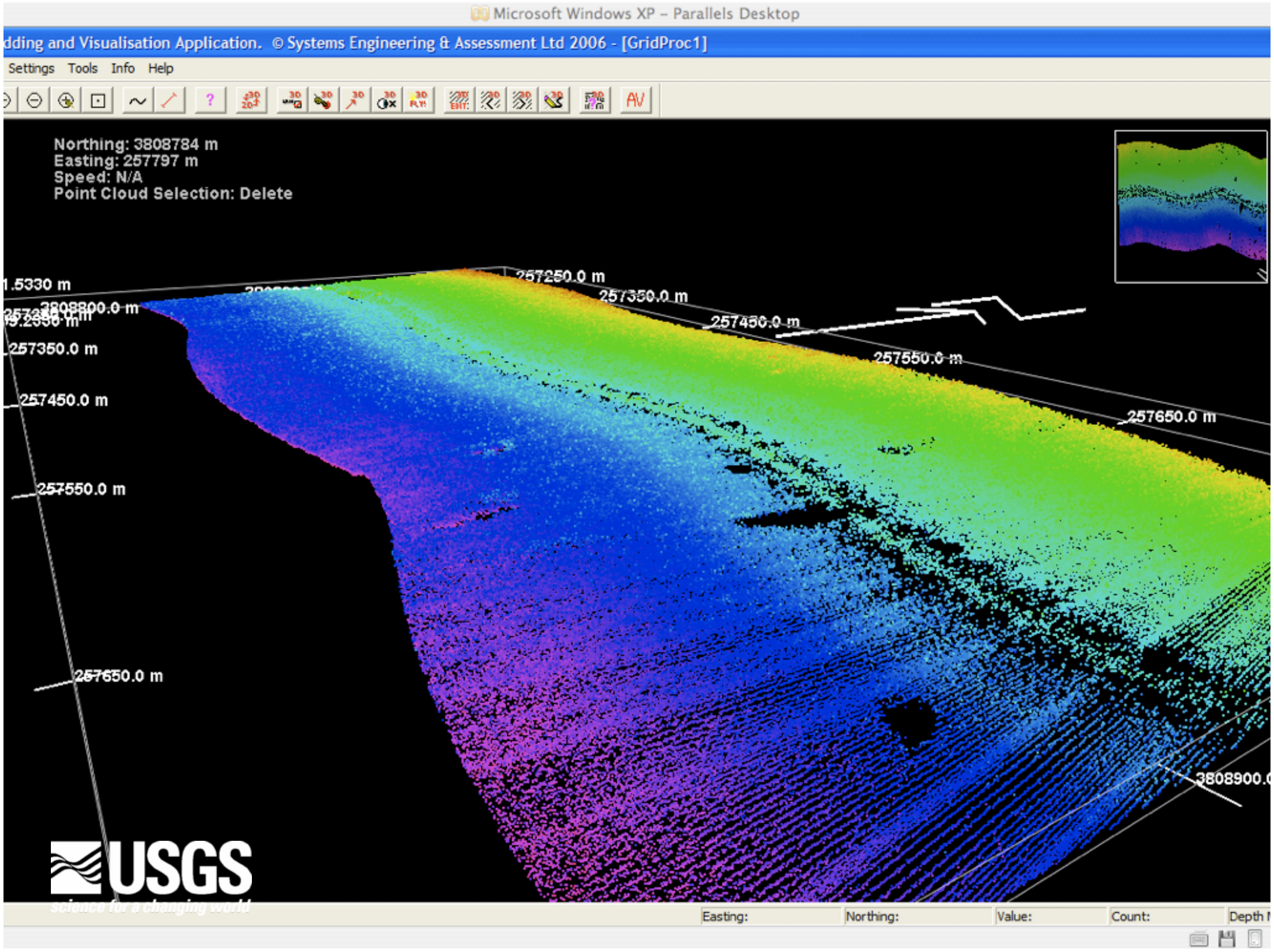
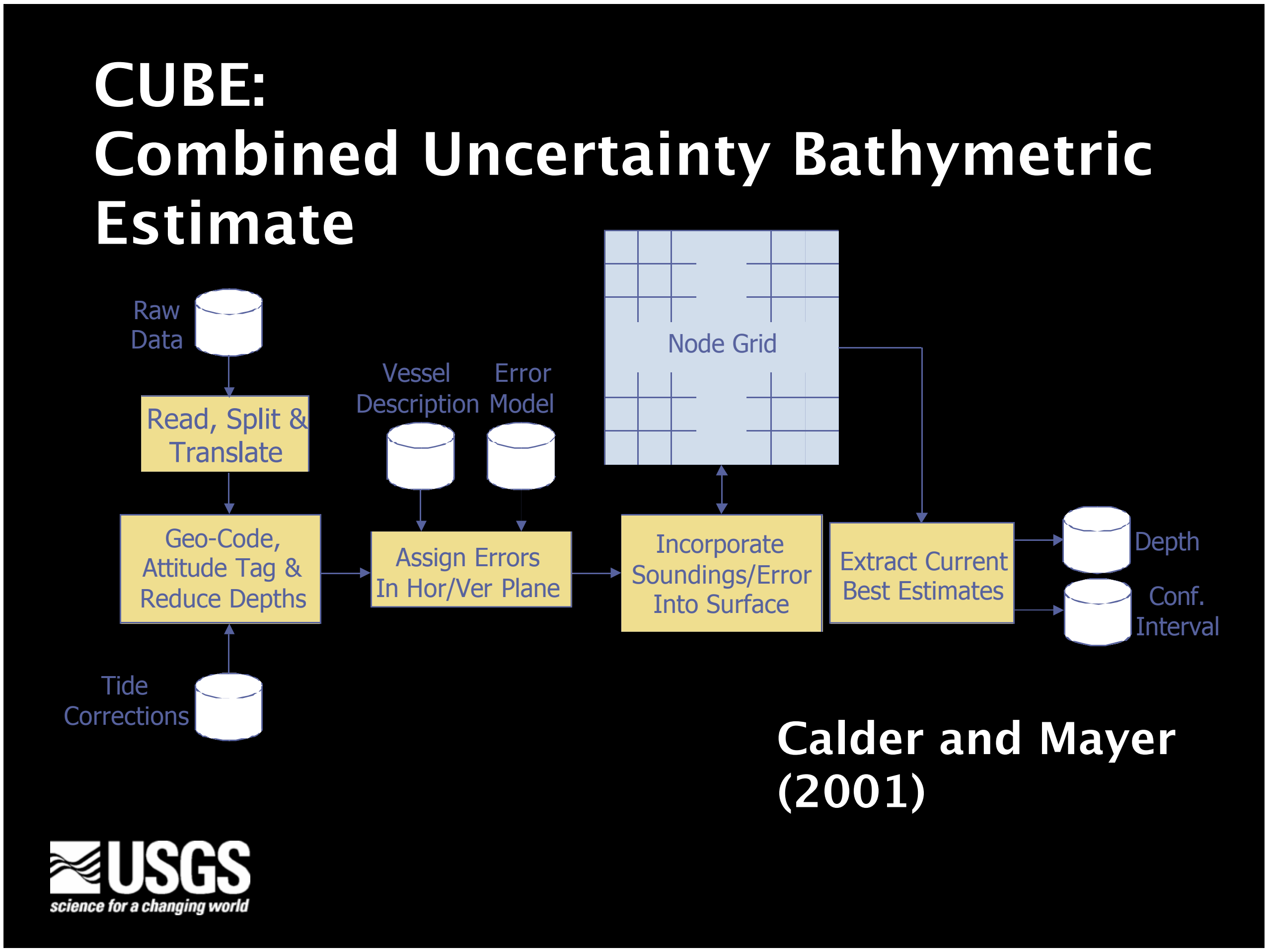
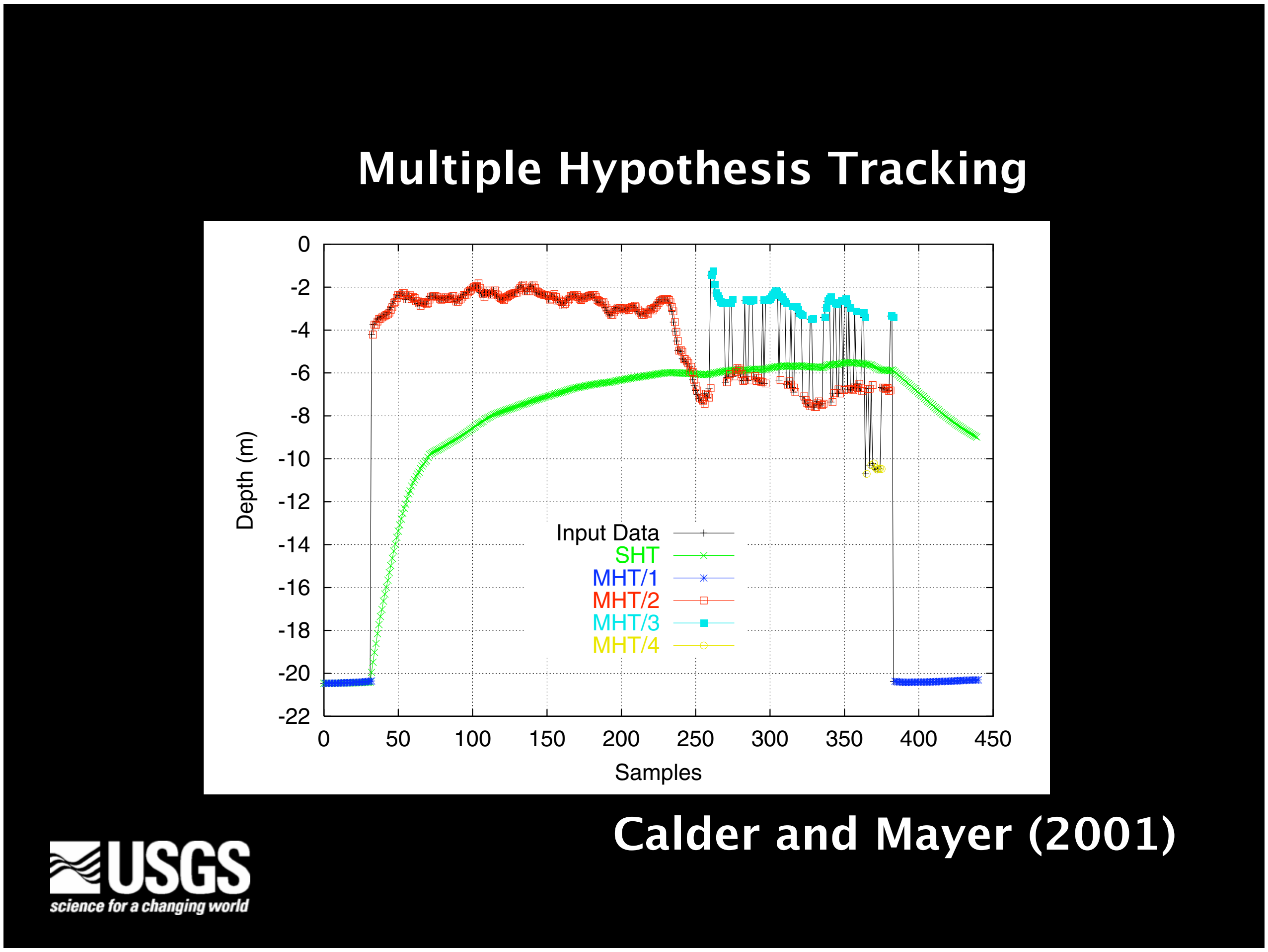
3D editing environments present millions of soundings for editing at once. Intuitive drag-and-drop interfaces work similar to drawing programs for editing problems in the data set. Shown above is the final surface.



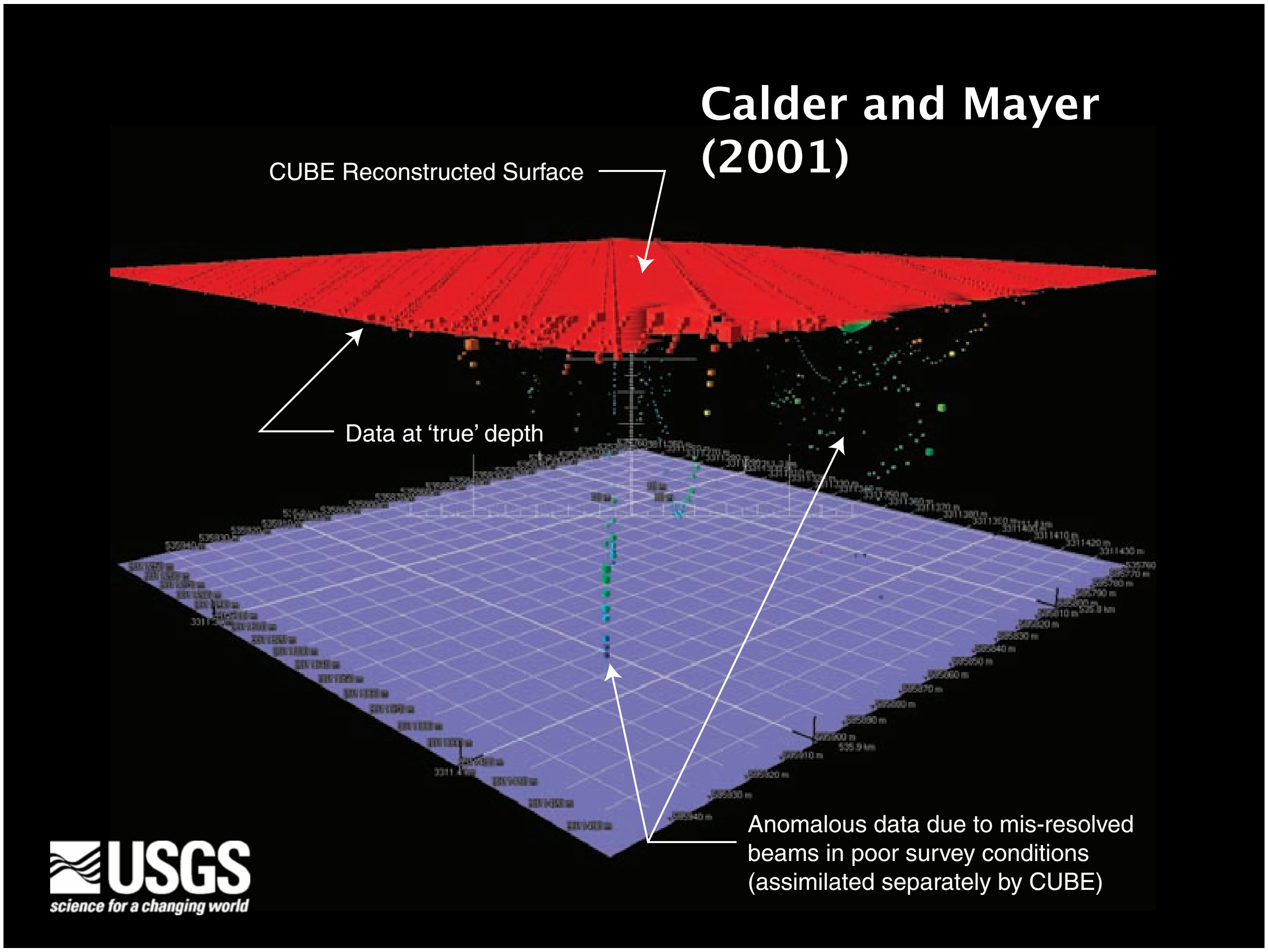
Shown here are the individual soundings where the operator can remove problem areas from the grid



The next level of automation is to “teach” the computer how to identify bad data more effectively. By measuring error sources in all equipment aboard the vessel and propagating these errors through the system, it is possible to tag each sounding with an uncertainty measurement. “Total propagated uncertainty”



Multiple hypothesis tracking is an advanced interpolation algorithm that creates multiple surfaces from the input data and attempts to pick the surface that most represents the intended data. In this case the blue and red data are correct, while the cyan and yellow data are noise. An old-fashioned moving average does not properly track the data because it is slow to adjust upward to the red line and because it includes the noise. A more sophisticated program (perhaps with user-interaction) would identify the red line as the correct surface.



This example shows how multiple hypothesis tracking can be presented to the user in 3D.

Goals of Sonar

1. Produce the most realistic representation of the sea floor possible
2. Processing should be near real-time
3. Maximize the number of products produced from a single survey

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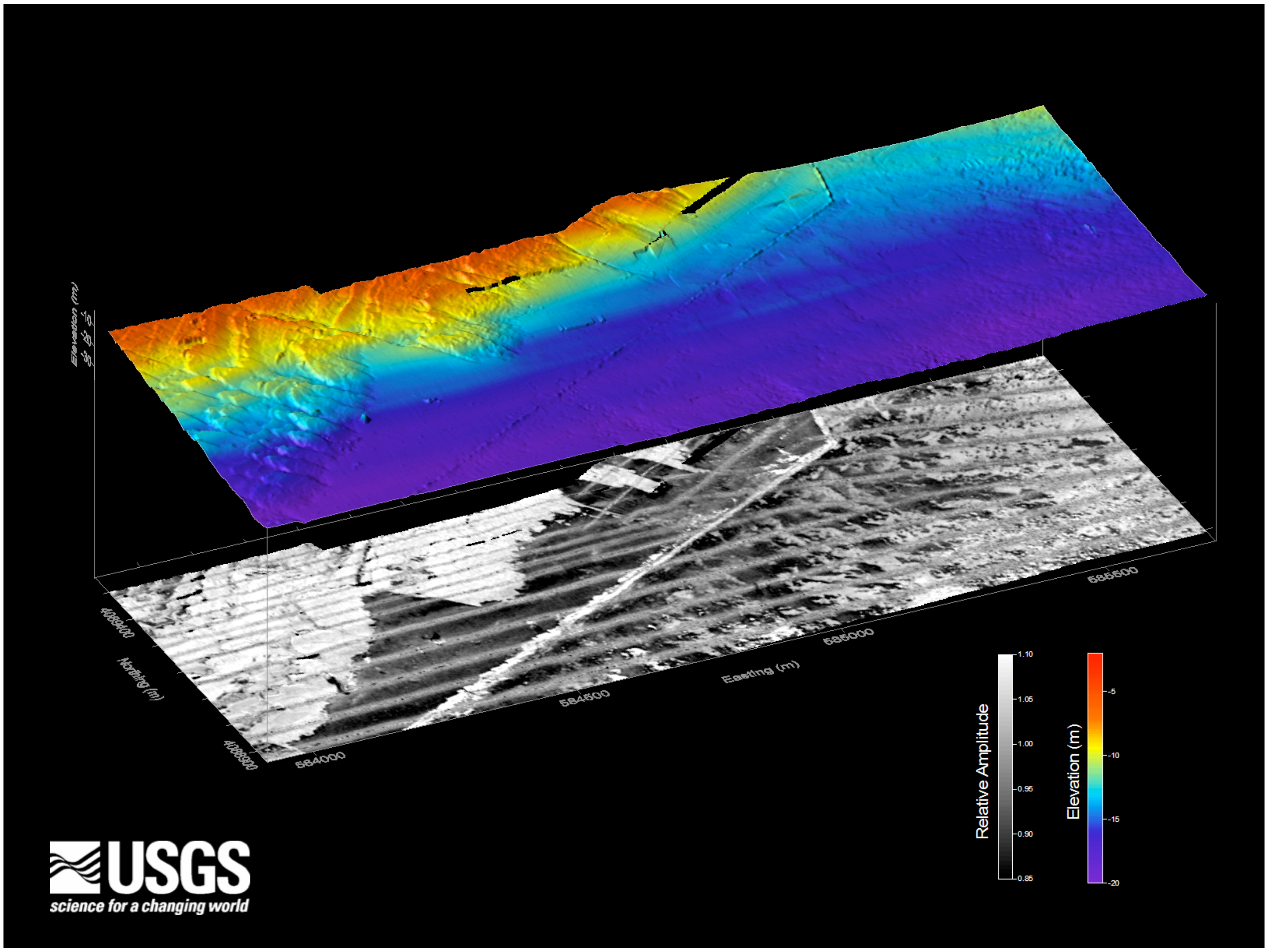
Elevation (m)
Northing (m)
Easting (m)
584000
584500
585000
585500
Relative Amplitude
1.10
1.05
1.00
0.95
0.90
0.85
Elevation (m)
-5
-10
-15
-20
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