Managing systematic residual errors in multibeam backscatter data

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ABSTRACT:

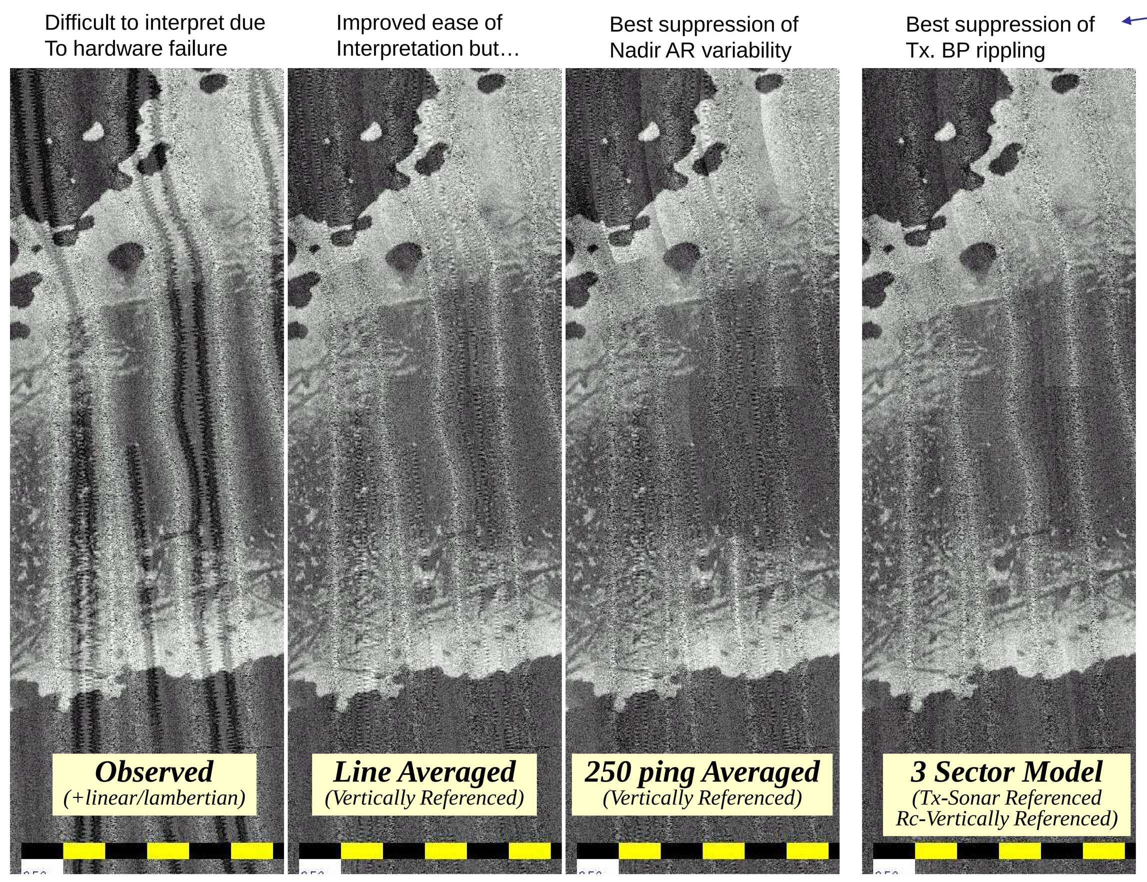
In support of the Geoscience for Ocean Management Program of the Geological Survey of Canada in the Queen Charlotte and Georgia Basins, over 400 ship-days of EM1002 multibeam sonar data have been collected through five field seasons. One requirement of these mapping activities is to have the ability to discriminate variations in seabed physical properties through the measurement of seabed backscatter strength estimates. While the information content of the initially processed backscatter data is remarkable, a number of systematic residual errors significantly compromise its usefulness for quantitative analysis.

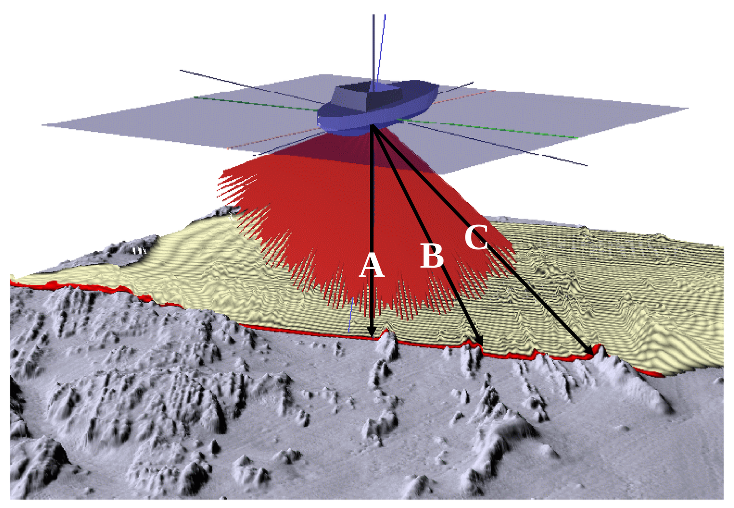
The backscatter data would ideally be properly reduced for all geometric and radiometric corrections. Unfortunately, there were a series of systematic hardware malfunctions that introduced a time-varying artifact in the data that was not corrected in the field. As a result, the data are compromised with a slowly varying signature that overprints the true seabed image, hampering quantitative analysis.

The principal problem was beam pattern residuals resulting from a combination of transmit and receive radiation sensitivities. The EM1002 uses roll stabilized receiver beams in three vertically referenced sectors. In contrast, the transmit beam patterns are fixed in the sonar reference frame. Thus the resulting artifacts are a mixture of vertically and sonar-referenced signatures. Overprinted on this is the seabed grazing angle variability (of interest for sediment classification), which is referenced to the local seabed slope and refracted ray path. As a result, standard combined grazing angle and beam pattern removal functions are inadequate. A new approach is described herein that tries to model and remove these effects. A secondary effect seen was imperfectly measured pulselength-related source level changes. These offsets changed as the sonar hardware and software were altered over the five year survey period, requiring local, empirical estimates of these offsets.

An additional problem with a subset of the data is that the full trace backscatter data were not collected. A reduced version of the data are still available in a beam-averaged form. These data, however, have a significant loss in spatial resolution and are not amenable to textural classification approaches. Methods are described herein that show how the beam-averaged data are used as a substitute. The loss of spatial resolution is shown. With the 200% overlap approach used during multibeam data acquisition, the highest resolution full trace data is actually lost in standard mosaicing. Azimuth specific images are generated that illustrate how this extra resolution can be viewed and used for enhanced interpretation.

Once beam pattern residuals are minimized, the remaining shiptrack-linked feature in the mosaics is the fact that the shape of the angular response curves vary as a function of lithology. While this is a real observation, it is disconcerting to the typical interpreter. A method that extracts the local shape of the angular response to facilitate normalization to an equivalent angle-invariant measurement is thus described. The same local normalization function can be used as a classifier. Examples of these are presented.



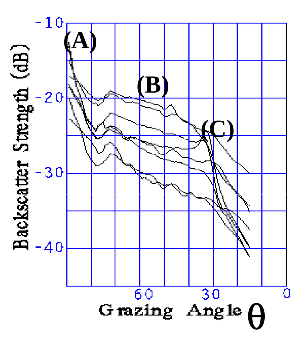


Bottom Backscatter Strength

Angular Dependence

(built into swath imaging geometry)

An opportunity to assess relative importance of different scattering mechanisms

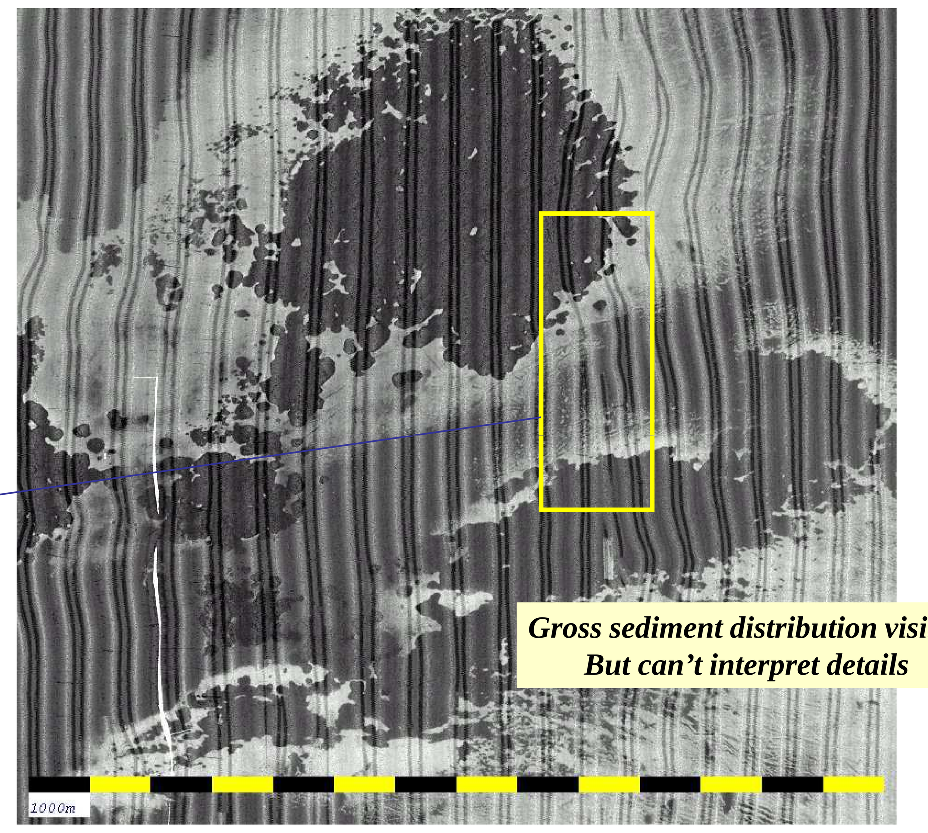


Interpretation issues with Grazing-Angle Invariant Backscatter Maps

As-Observed backscatter variability – with strong artifact

These data show the direct output of the Simrad beam trace telegrams. The data are reduced for source power, pulse length, TVG and designed beam patterns. An additional combined linear and lambertian grazing angle model is applied to hide the main grazing angle effect.

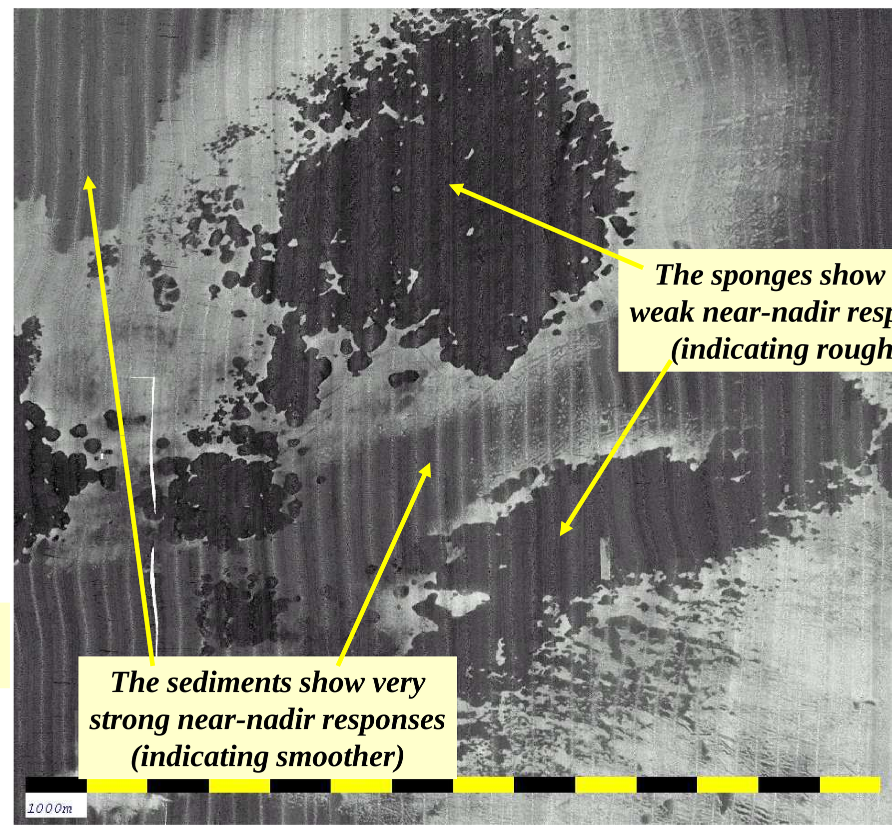
Because, however, of operational hardware problems with the TRB's a pronounced null was present on the starboard side of the inner (98 kHz) sector. These nulls roll in the sonar-reference frame and overprint the true geological signature. Subtle variations in the shape of the seabed angular response (AR) and fine scale patchiness are lost as a result.



Beam pattern reduction using line-averaged statistics

In this case we estimate the average variation in observed backscatter as a function of vertically-referenced angle on a line-by-line basis. Because lines were typically ~1 hour long, many different sediment types are observed within the averaging region. The resulting combined beam pattern and grazing angle response is a compromise, mixing sediment types with both strong and weak near-nadir responses.

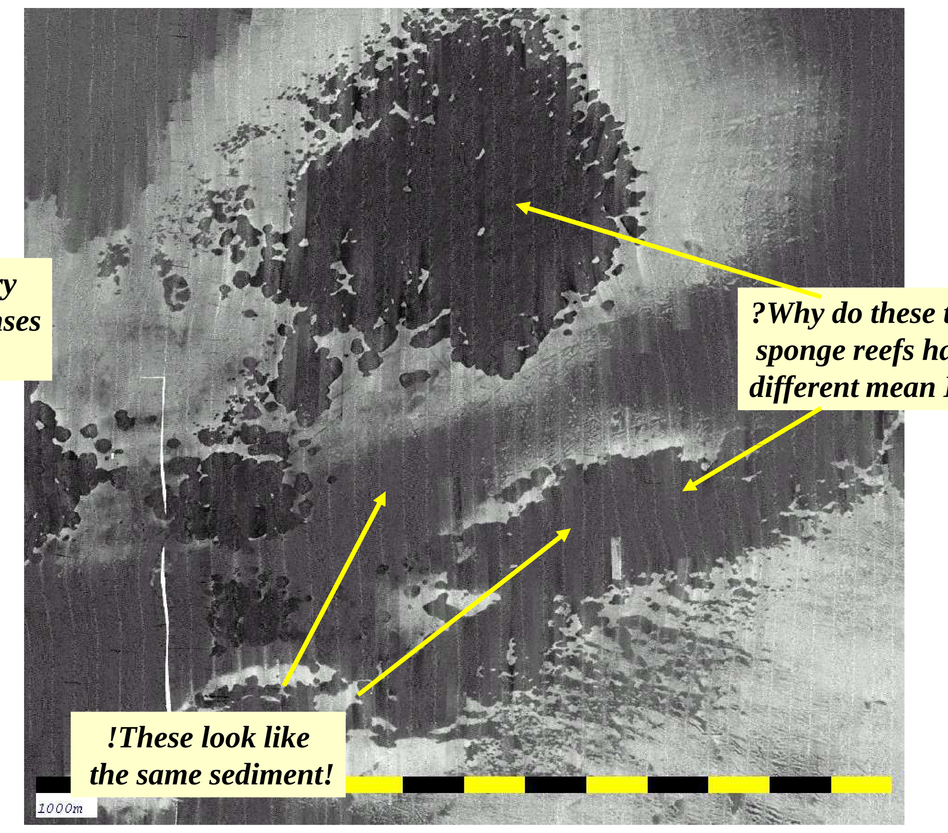
As a result, while the systematic beam pattern artifact is gone, one now can see variations in the shape of the angular response curve from sediment to sediment. These were previously obscured by the gross beam pattern artifacts.



Beam pattern reduction using rolling 250-ping statistics

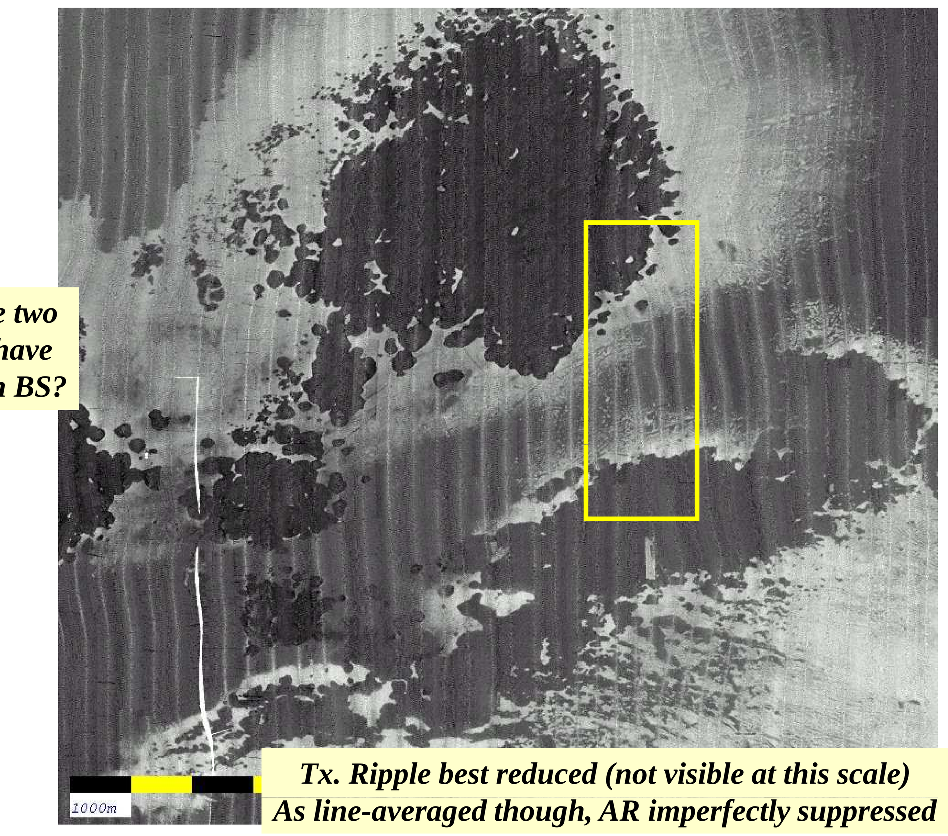
Note how the high grazing angle data are well accommodated by using a local estimate of the angular response. The unavoidable consequence, however, is that any lateral (i.e.: across-track) geological variability (that is stable over a 250 ping window) is confused with the beam pattern signature. As a result one sees "haloes" wherever the vessel obliquely traverses a significant geological boundary.

As the variations in near nadir response are suppressed, though, one can actually fail to recognize the difference between sediments whose AR only differs at high grazing angles.



Beam pattern reduction using 3 sonar-relative sectors.

In this case, as with the line –averaged beam pattern statistics, because a typical line crosses multiple sediment types, the near nadir angular response is less well suppressed. What is not apparent at this scale however ,is that the rippling beam pattern nulls are far better suppressed (see zoomed detail below). What one can see is that there are areas, particularly of moderate backscatter strength that show marked variability in the near nadir response (see AR curves below) suggesting subtle sediment differences.



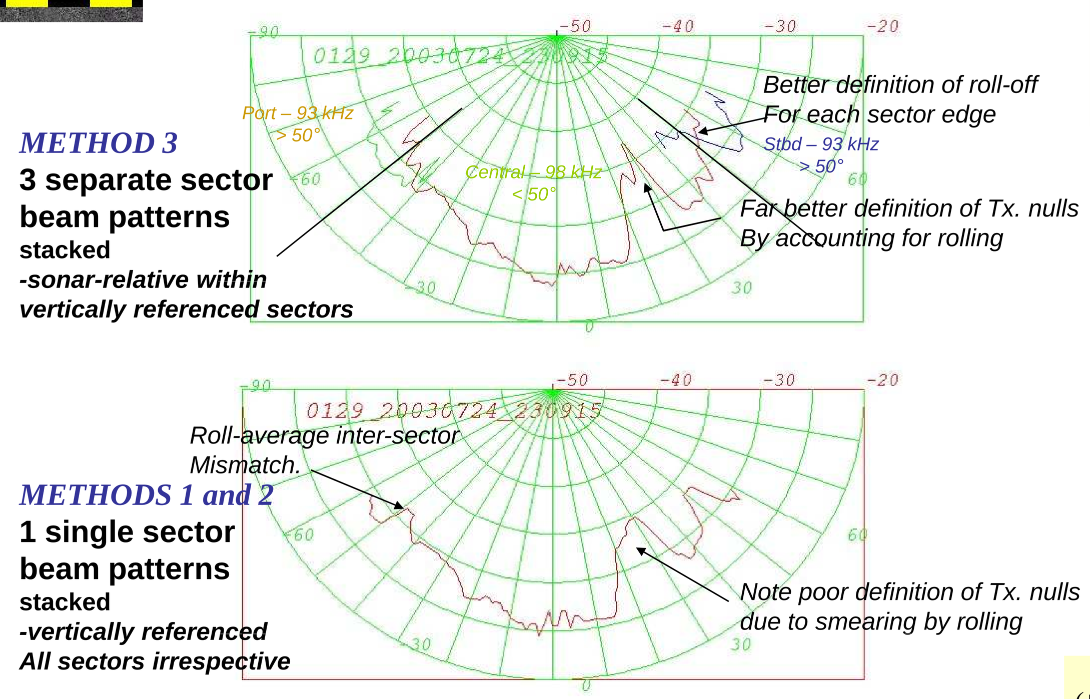
Alternate Methods for deriving Grazing-Angle Invariant Backscatter Maps

Estimating the Combined – Beam Pattern - Angular Response Signature

The underlying issue in presenting this data is that there are two effects seen in the backscatter mosaics that influence the variation of backscatter strength as a function of imaging geometry.:

1. Beam Pattern Signatures (of both the Tx. And Rc. Sensitivities)
2. Backscatter Angular Response Signatures (for the differing seabed types encountered

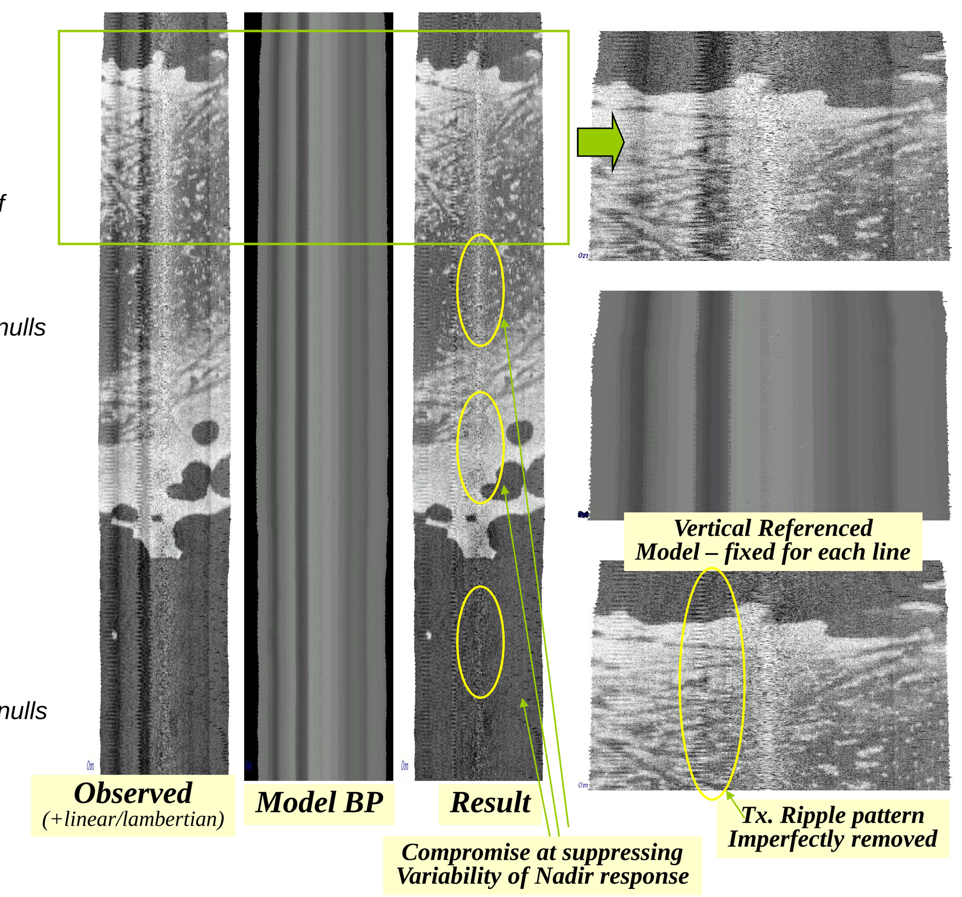
For each of the three methods, it is necessary to estimate this combined effect from the resulting seabed data. Assumptions need to be made about the contribution of Tx. And Rc. Beam patterns (how/whether stabilized and whether separated by sector), and the stationarity of the underlying seafloor type.



METHOD 1 : Estimating the Line-Averaged Variability in the Vertically Referenced Angle

The simplest approach to removing the combined beam pattern and seabed angular response is to assume that both can be approximated by stacking the vertically reference incidence angle (in this case over several 1000 pings within a file to average out geological variance). This however, assumes :

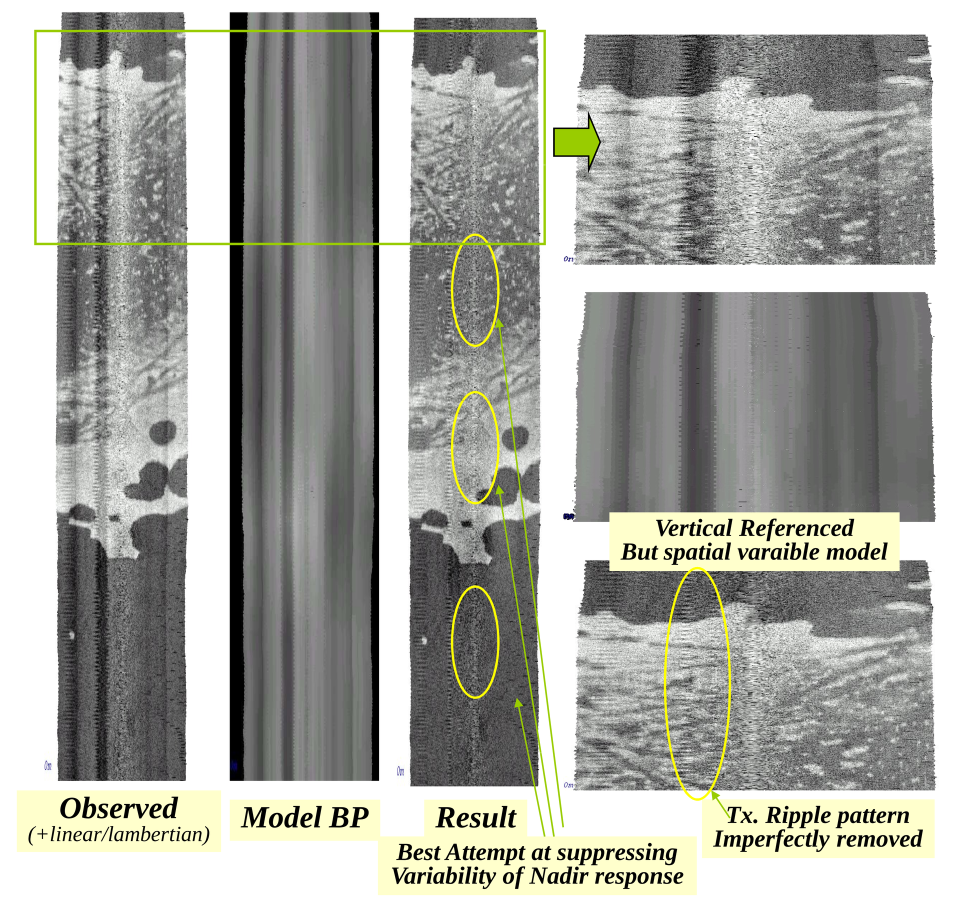
1. that the difference between grazing (90-) and incidence is insignificant (**low seabed slopes**)
2. that ***the shape of the angular response curve is invariant*** amongst sediment types.
3. That the beam pattern signature is **controlled predominantly by roll stabilized electronic** beam steering (i.e. beam amplifiers, not physical characteristics of the array).



METHOD 2 : Estimating the Local (250 ping) Variability in the Vertically Referenced Angle

Recognizing that the shape of the angular response curve DOES vary with sediment type, to try and locally compensate for grazing angle variation, the LOCAL shape of the curve must be estimated. This can be attempted by stacking the variation by incidence angle over short spatial distance (short w.r.t. the distance over which seabed changes commonly take place).

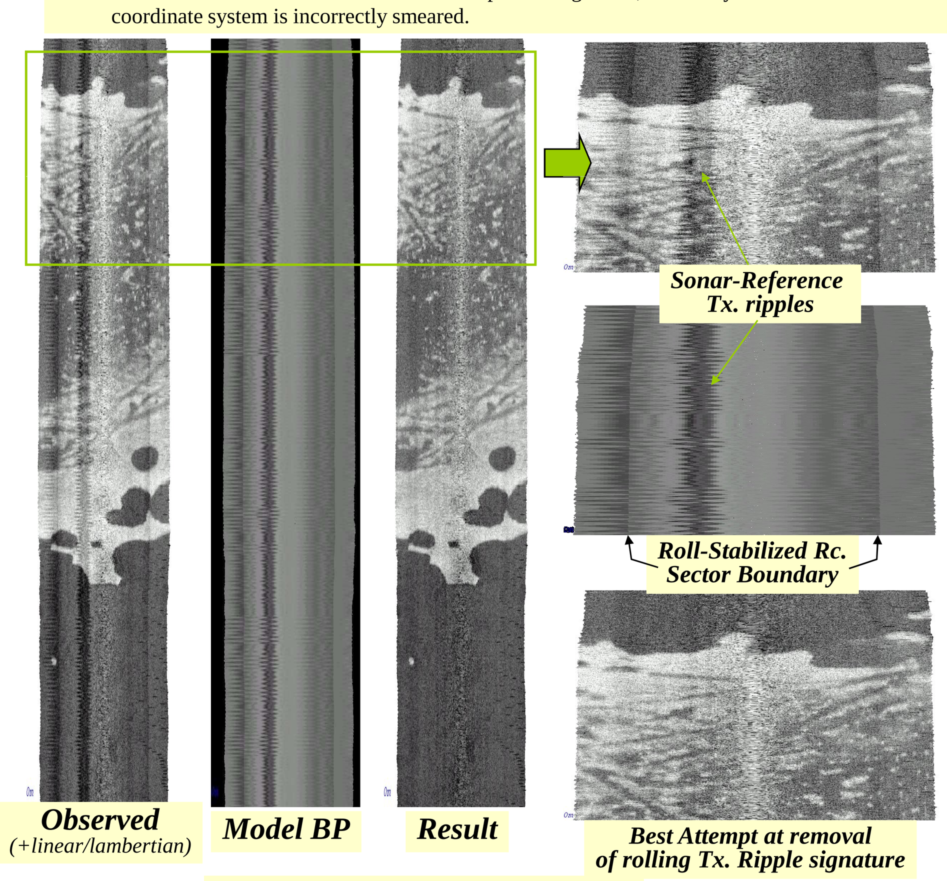
- This has the advantage that the shape of the angular response CAN change locally BUT
- Has the disadvantage that it is sensitive to across track variations in lithology that are sustained over the shorter spatial stacking distance.



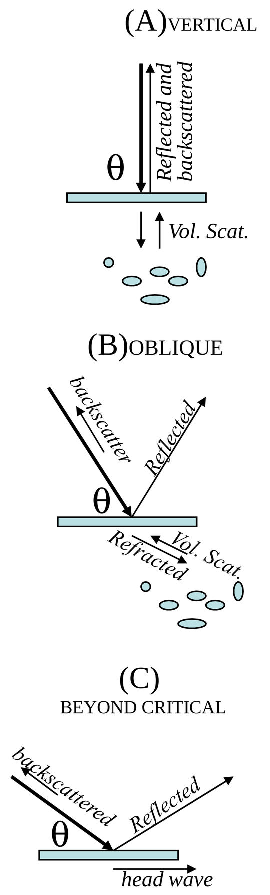
METHOD 3 : Estimating the Line-Averaged Variability in three Sonar-Referenced Tx. Sectors, that are truncated within 3 Vertically Referenced Rc. Sectors

This approach best models the attributes of the Simrad EM1002 electronics. Although the Receiver Channels are vertically stabilized, it is clear that the dominant ripple-like artifact is rolling in a sonar –relative framework. They must therefore be associated with the transmit beam patterns.

1. Clearly **improves the suppression of the rippling beam pattern nulls**. This improves the likelihood of definition of fine-scale seabed geological varability.
2. Falsely assumes that the grazing angle signature may be approximated by a sonar-relative reference frame. As a result the near nadir specular signature, that really is fixed in the seabed coordinate system is incorrectly smeared.



Additional Discrimination using Angular Response



Deriving the shape of the backscatter angular response as an additional classifier

If these systematic residual errors in the EM1002 backscatter strength estimates can be adequately modeled and reduced, we stand to gain in two ways:

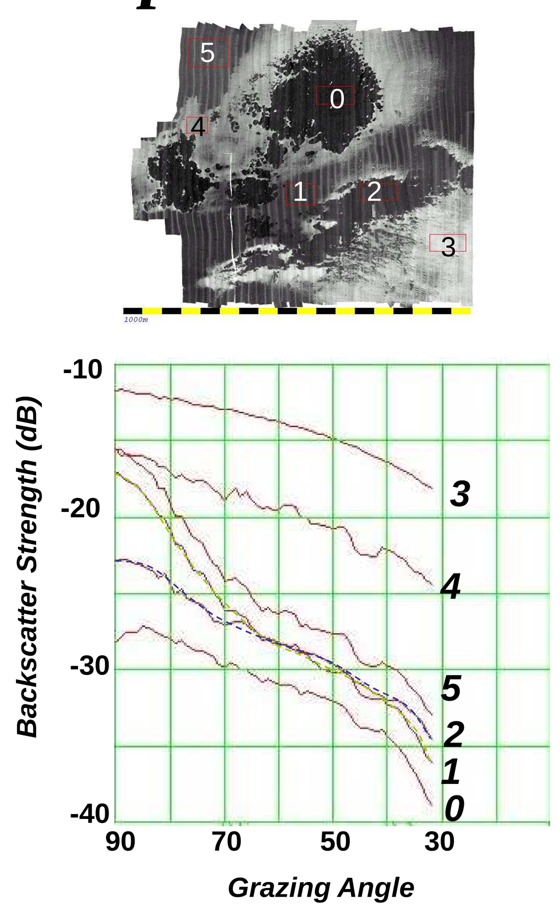
•Firstly, by suppressing the visibility of the grazing angle and beam pattern signatures, the interpreter can focus on regional sediment distribution patterns (from the angle-invariant mean backscatter characteristics) without falsely inferring geological boundaries based on changing imaging geometry.

•Secondly, once the beam pattern overprint is removed, the true shape of the backscatter angular response may be ascertained locally from within areas that are clearly of homogenous character. For example, areas 1 and 5 (map to right upper) show a markedly specular signature (curves on figure right lower). In contrast, areas 0 and 2 (the sponge reef complexes), clearly have a reduced specular signature. If however, area 1 and 2 were examined in isolation, based on angle invariant character (normally associated with BS values at ~ 45°) they would appear to be similar sediment types (see central figure above utilizing Method 2).

Areas 3 and 4, that are clearly high backscatter (i.e. high impedance contrast, probably gravel lags?), show typical near-lambertian responses, implying also rough.

The implication is that the sponge reefs share similar surface roughness characteristics to the gravels, but with markedly lower impedance contrasts.

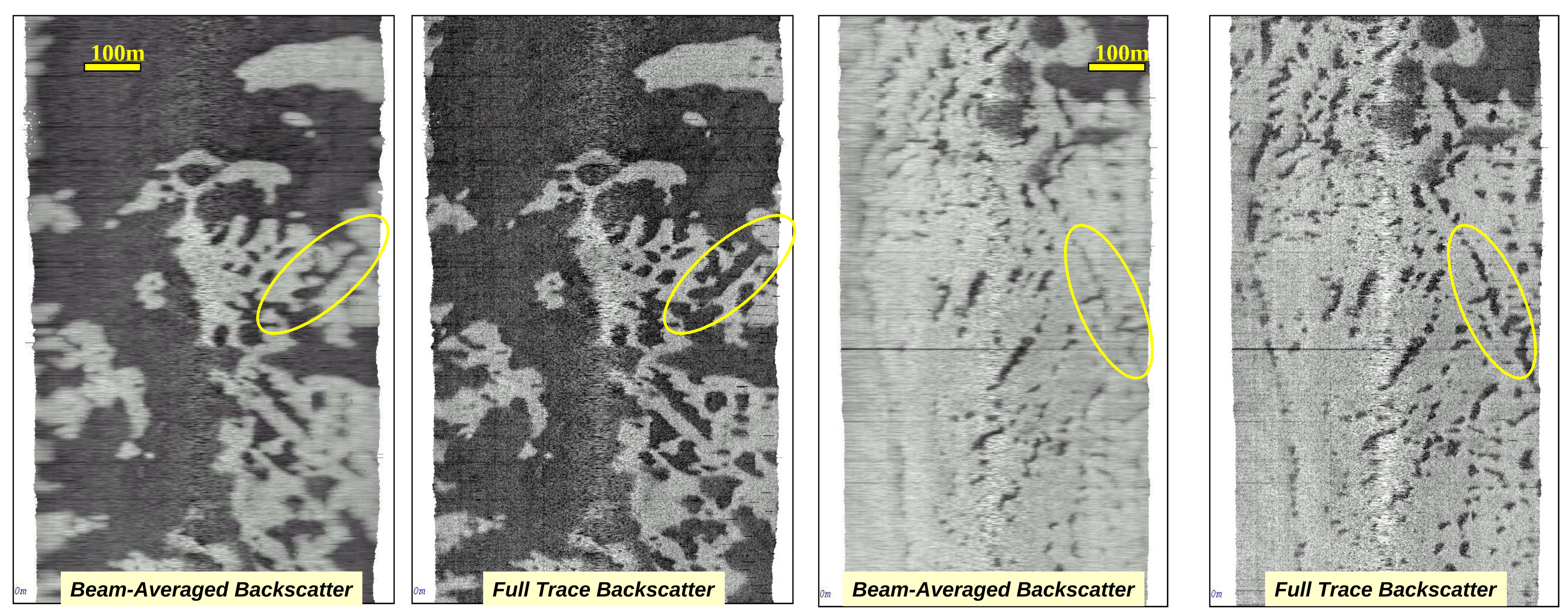
For the weaker sponge reef signatures (e.g. 0), there is a suggestion that critical angle kink is seen that could allow one to infer the interface surface sound speed ratio directly. As the EM1002 was only employed at +/60° sector, we cannot however, assess whether critical angle effects exist for the other lower sound-speed sediment types (would require logging wider angular sectors to catch the lower grazing angles).



Using Beam-Averaged Data: Resolution Loss and Feature Distortion

For a significant fraction of the 1999-2002 survey data, the full beam trace information was accidentally not logged. As a substitute, it is possible to retain a "beam averaged" subset of the trace data (recorded in the depth telegram). This data, contains similar, but not identical spatial attributes. The three prime causes of concern are:

1. The data are averaged, and therefore, ***the speckle character (textural information) of the data is lost*** (used for short wavelength spatial statistics).
2. The same averaging ***reduces the effective spatial resolution to 2x the beam spacing***. This results in loss of detail in the seabed image (losing fine scale patchiness definition).
3. The data are not actually a simple average, but rather, an average of the strongest section of the beam trace data. As a result, for footprints that overlap sediment boundaries, the ***spatial extent of the low backscatter sediment can be grossly underestimated***.



Because the CHS routinely employ 200% coverage survey procedures (to improve the reliability of target detection), standard mosaiced data lose the low grazing angle imagery in which the best detail is preserved (unlike the bathymetry in which the best detail is near nadir).

That low grazing angle backscatter imagery can be viewed by selecting azimuth-restricted images (looking alternately to NE or SW in the case of the example below). This reveals extra detail not otherwise available to the interpreter.