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Adjustment of backscatter data collected by multi-sector multi-swath multibeam echo sounders

An article by JEAN-GUY NISTAD

While technological innovation and good survey practice has rendered bathymetric data collection more efficient and measurements both precise and accurate, so much cannot be said about backscatter data. Indeed, being more sensitive to geometrical, environmental and system-dependent effects, backscatter measurements suffer from poor quality when the latter effects are not accounted for in data collection and processing steps. A major detrimental component on backscatter measurements is the modulating effect of the echo sounder's transmission sector pattern(s). This effect is clearly seen in backscatter images from echo sounders with multi-sector and multi-swath capabilities.

backscatter strength | SonarScope | multibeam echo sounder

Introduction

Given the capability of modern swath bathymetry multibeam echo sounders to collect co-registered backscatter data of the seabed, it has become a common task for many surveying organisations to collect this information in an opportunistic manner. While technological innovation and good survey practice has rendered bathymetric data collection more efficient and measurements both precise and accurate, so much cannot be said of backscatter data. Indeed, lack of well-established measurement references and data processing standards has led to a situation where backscatter data may not meet precision and accuracy requirements.

A major detrimental component on backscatter measurement is the modulating effect of the echo sounder's transmission sector pattern(s). In post-processing, this modulation cannot be distinguished from the angular dependence of the backscatter strength (BS), a best estimate of the seafloor acoustic reflectivity, itself an inherent property of the seafloor that varies only with the incidence angle to the seafloor for a given acoustic signal frequency. Traditional statistical angular correction methods simply compensate for both effects simultaneously. However, as the BS angular response should be considered the de-facto backscatter measurement reference, there is a need to separate the respective contributions of the BS and the transmission sector pattern(s). Only through a dedicated field calibration procedure can the latter be accounted for and compensated.

While the modulating effect of single-sector multibeam echo sounders is not visibly apparent in real-time backscatter measurements, poorly-compensated or uncompensated transmission sector patterns of multi-sector multi-swath multibeams may be visibly apparent. Such was the case for the Canadian ice-breaker and research vessel Canadian Coast Guard Ship (CCGS) »Amundsen«. Using a field calibration procedure developed by the Institut français de recherche pour l'exploitation de la mer (IFREMER), an attempt was undertaken to properly calibrate the transmission sector patterns of the ship's multibeam echo sounder. This article presents the method, analysis and results of this attempt.

Multi-year surveys in the Canadian Arctic Archipelago

Since the year 2003, the Canadian ice-breaker and research vessel CCGS »Amundsen« has been conducting continuous seabed mapping operations as part of a multi-disciplinary research programme. For seabed mapping operations, the ship is fitted with a Kongsberg Maritime (KM) EM302 30 kHz multibeam echo sounder (MBES). The EM302 is a mid-ocean depth, multi-sector, multi-swath multibeam echo sounder suitable for the depth range of the Canadian Arctic Archipelago (0 to ~3000 metres). Fig. 1 presents 30′ longitude by 9′ latitude bathymetry and backscatter maps of multibeam data collected on two occasions (September 2nd and 9th, 2014) while the ship was transiting in the southern Beaufort Sea. While the digital terrain model (DTM) of Fig. 1a demonstrates good consistency, the backscatter mosaic of Fig. 1b does not.

The backscatter mosaic of Fig. 1b is the result of the Kongsberg real-time data reduction process, which aims at obtaining a best estimate of the angular compensated BS by accounting for all system-dependent, geometrical and environmental components inherent in a complete transmission-reception cycle. The angular dependence of the BS is removed using a simplified Lambertian decrease model. Given their geometry and orientation, changes in BS values visible in the backscatter mosaic cannot be correlated to changes in the composition of the substrate, but rather to inaccuracies in the Kongsberg real-time data reduction process. These changes occur both between survey lines and within individual survey lines. Being more fundamental, the intra-line artefacts need to be addressed first.

Intra-line artefacts taking the form of along-track bands can easily be traced back to changes

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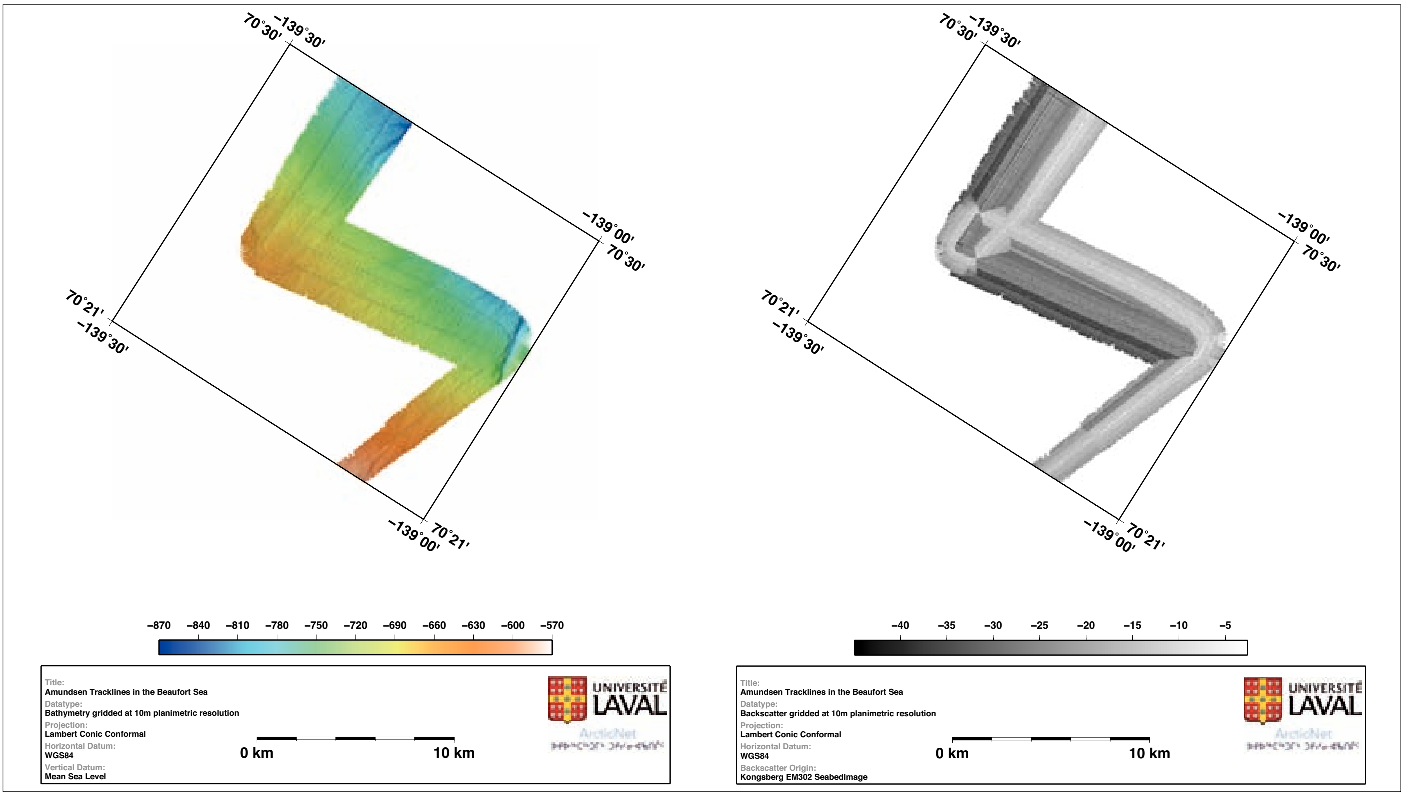

Fig. 1: Basemap tiles of the Canadian Arctic Archipelago from data collected in 2014 with the bathymetric surface (a, left) and the first-order angular compensated BS mosaic (b, right)

in the echo sounder's runtime parameters. Fig. 2 illustrates the correlation between changes in the BS and changes to the Depth Mode parameter. The Depth Mode, Swath Type and Pulse Type are three parameters that collectively determine the Transmission Mode of the echo sounder. While not depicted in the Fig., changes in Swath Type and Pulse Type are also likely to induce changes to the BS level of survey lines. During normal operation, the EM302 will automatically find the most appropriate combination of Depth Mode, Swath Type and Pulse Type (i.e. Transmission Mode) to fit the current range to the bottom and along-track data density. Each Transmission Mode uses a number of transmission sectors with each sector's pattern possessing a unique signature. EM302 echo sounders actually do compensate in real-time for the sector patterns. However, they utilise default models which do not necessarily reflect the real patterns. Any discrepancy between the models and reality will lead to residual overprinting visible on the backscatter level of individual survey lines, a situation clearly visible in Fig. 1b. Luckily, the sector pattern models can be adapted by appropriately modifying a configuration file known as the *bscorr.txt* file. With an appropriately configured *bscorr.txt* file, no further modulation of the sector patterns will be visible in the real-time collected data.

IFREMER backscatter calibration procedure

Attempts to calibrate echo sounder beam patterns are not new. Foote et al. (2005) and more recently Lanzoni and Weber (2010) have detailed procedures to achieve such results under controlled settings. However, these procedures are limited to relatively compact and high-frequency echo sounders. For medium to deep depth echo sounders, this type of

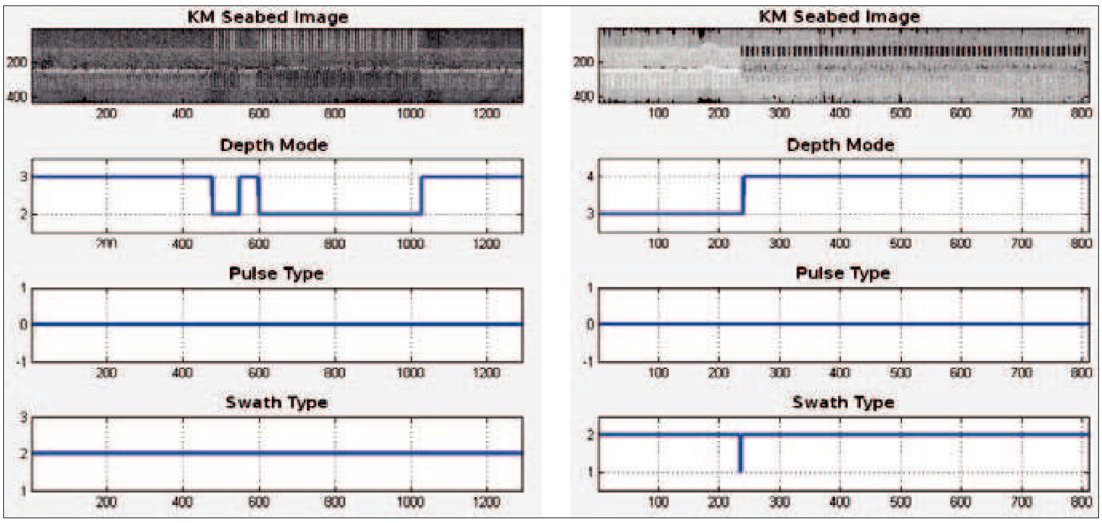

Fig. 2: Angular compensated BS images in ping vs beam geometry (direction of travel left to right) and parameter values of the Transmission Modes used in two survey lines (Depth Mode: 2 = Shallow; 3 = Medium; 4 = Deep. Pulse Type: 0 = CW; 1 = FM. Swath Type: 1 = Single; 2 = Dual)

calibrated setup is not possible in a laboratory environment due to the size of the instruments and acoustic range requirements. Deviations from the laboratory measurements are also likely to occur following the final installation configuration on board a ship and due to normal wear and tear of electronic and acoustic components. For these reasons, it is imperative that a field calibration procedure be performed to account for the sector patterns of medium and deep sea multibeam echo sounders.

The calibration procedure developed by IFREMER aims at more accurately modelling the sector patterns of multi-sector, multi-swath multibeams by direct analysis on real-time collected backscatter images. To be successfully completed, the procedure requires a calibration survey to be performed and subsequent analysis of the backscatter images using the IFREMER software SonarScope. The calibration survey areas must be chosen carefully in order to optimise the quality of the analysis. Flat, suitably deep and geologically uniform seabed areas must be pre-selected for the calibration survey. A series of opposite running survey lines are then run for each Transmission Mode.

Such a calibration survey and subsequent backscatter data analysis was performed for the EM302 of CCGS »Amundsen«. The figures demonstrate the effectiveness of the procedure. The Shallow, Dual, CW Transmission Mode is used as a case example.

Fig. 3a shows the angular compensated BS image in ping vs beam geometry resulting from the Kongsberg real-time data reduction process for the Shallow, Dual, CW Transmission Mode. Fig. 3b shows the mean BS angular curve obtained from the BS image by averaging the BS values in 1° bins and colour-coding curve segments by unique transmission sector.

Step 1 of the calibration procedure consists in removing the BS angular response model used in

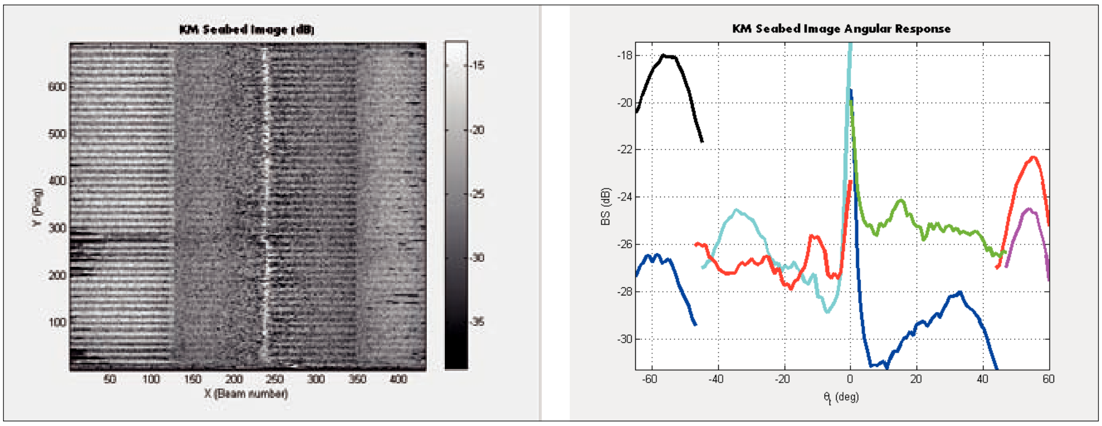

Fig. 3: Angular compensated BS image in ping vs beam geometry (a, left) and corresponding angular response (b, right) for the Shallow Dual CW Transmission Mode

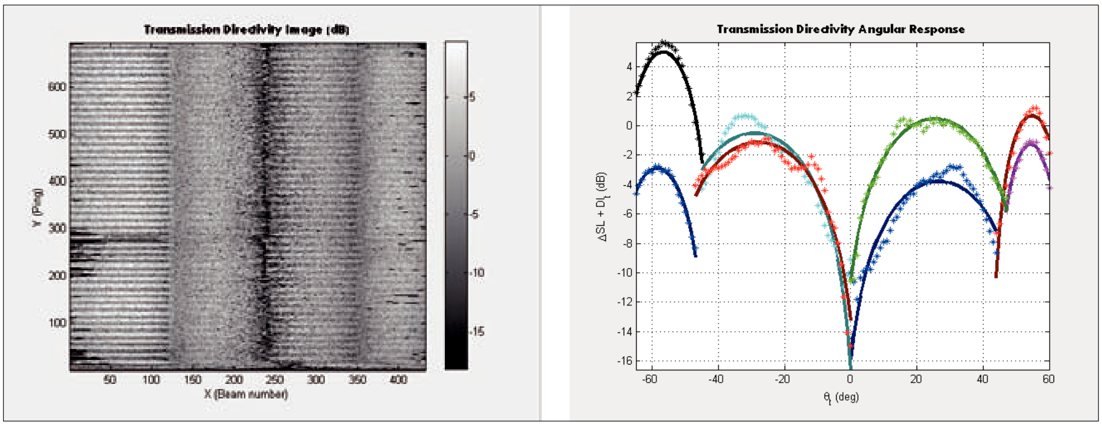

Fig. 4: Transmission sector patterns image in ping vs beam geometry (a, left) and corresponding angular response (points) and models (lines) (b, right) for the Shallow Dual CW Transmission Mode

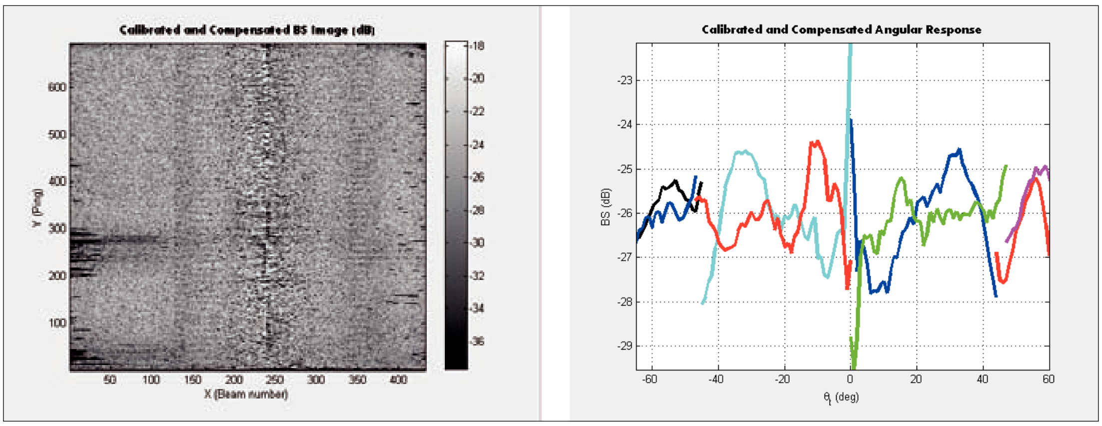

Fig. 5: Calibrated and angular compensated BS image in ping vs beam geometry (a, left) and corresponding angular response (b, right) for the Shallow Dual CW Transmission Mode

the Kongsberg real-time data reduction process from the angular compensated BS image in order to obtain an angular uncompensated BS image.

Step 2 consists in modelling the BS angular dependence visible in the angular uncompensated BS image. The Generic Seafloor Acoustic Backscatter (GSAB) model (Lamarche et al. 2011) is used for that purpose.

In step 3, the new »best« modelled estimate of the BS angular dependence is applied and the Kongsberg default transmission sector pattern compensation is removed. This process isolates the sector patterns, which can be »seen« in the backscatter image (Fig. 4a).

Finally, step 4 consists in modelling the transmission sector patterns as first-order polynomials, an approximation of the mathematically correct sinc function. Three parameters constitute the variables of the polynomial functions: the source level, the transmission angle and the sector opening angle. Fig. 4b shows the corresponding angular response of the residual colour-coded transmission sector beam patterns. The points represent the mean source level residual per 1° bin and the continuous lines represent the modelling of the transmission sector patterns.

Results

The newly modelled transmission sector patterns can be applied to the survey data to assess the quality of the calibration. Fig. 5a shows the angular compensated BS image in ping vs beam geometry for the Shallow, Dual, CW Transmission Mode with the new transmission sector patterns and GSAB models applied. Fig. 5b is the corresponding mean BS angular response. While some modulation is still visible in the BS image, especially at the sector boundaries, the overall precision of the mean BS angular response is significantly improved. Fig. 6 illustrates the precision improvements of the angular compensated mean BS in the 15 to 60 degrees angular interval for all operational Transmission Modes. The latter interval is chosen so as to exclude the nadir and grazing angle zones, which always comprise less reliable data.

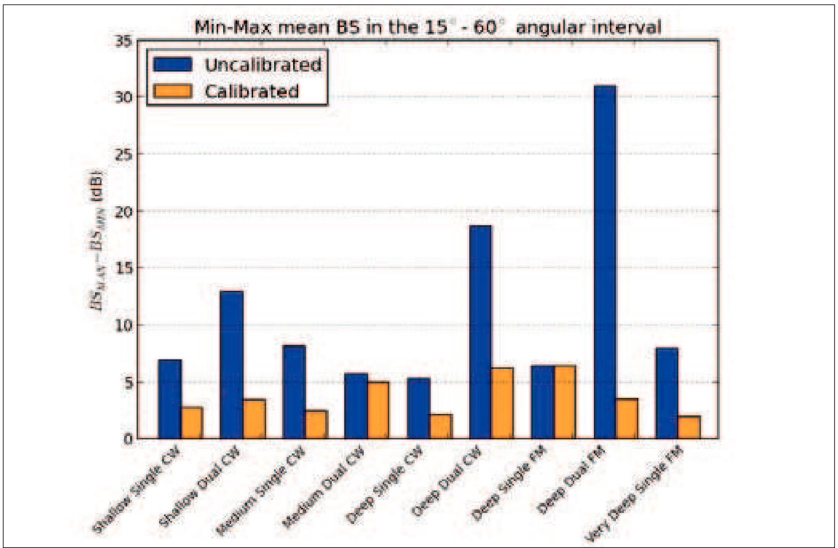

Fig. 6: Precision of the angular compensated mean BS in the 15 to 60 degrees angular interval for all operational Transmission Modes of the EM302 of CCGS »Amundsen«

The modelled transmission sector patterns resulting from the calibration can be utilised in two ways. First, the values of the models can be written in the *bscorr.txt* file and injected to the EM302 echo sounder. This will ensure that all newly collected data will be exempt from any modulating effect due to improperly calibrated transmission sector patterns. Second, the models can be applied to existing backscatter data in order to mitigate the intra-line artefacts. Fig. 7a illustrates the identical mosaic as in Fig. 1b with the transmission sector patterns properly calibrated. Aside from a BS minimum in the nadir area, no further along-track artefacts are visible.

Several attempts were undertaken to discover the reason for the remaining inter-line bias in Fig. 7a. This 10 dB bias between the survey line collected on September 2nd and the one collected on September 9th could not be explained by changes to environmental factors (changes to the seabed type or to the water column properties). The only conclusive explanation stems from the software instabilities experienced during the surveys. These were correlated to an incompatibility between hardware and software versions which necessitated the complete re-installation of the data collection software after the first and before the second survey. This type of problem cannot be accounted for in post-processing other than by applying a statistical angular correction whose result is illustrated in Fig. 7b. Although the backscatter mosaic now appears uniform, one cannot speak of absolute BS levels since a bias has been introduced.

Discussion and future improvements

While the proper calibration of transmission sector patterns is a step towards absolute and properly referenced backscatter data, transmission sector patterns are not the only factor that needs to be addressed. Other factors include:

- proper compensation for absorption of the acoustic signal in the water column;
- accounting for the topography of the seabed when calculating the ensonified area;
- possible compensation for the receive beam patterns;
- the need for a bathymetry surface except of outliers and biases.

Several of these factors could not be or were simply not fully addressed during the calibration survey and subsequent data analysis. Logistical and time constraints help explain why the calibration survey could not be performed under ideal conditions. Given the multi-disciplinary nature of the research conducted on CCGS »Amundsen«, this is to be expected. Limitations in the workflow used to transfer the raw data collection measurements to a bathymetry processing software and finally to SonarScope are also a root cause for sub-optimal results.

However, the single greatest weakness of the calibration procedure is the reliance on the modelled BS angular response from the empirical data.

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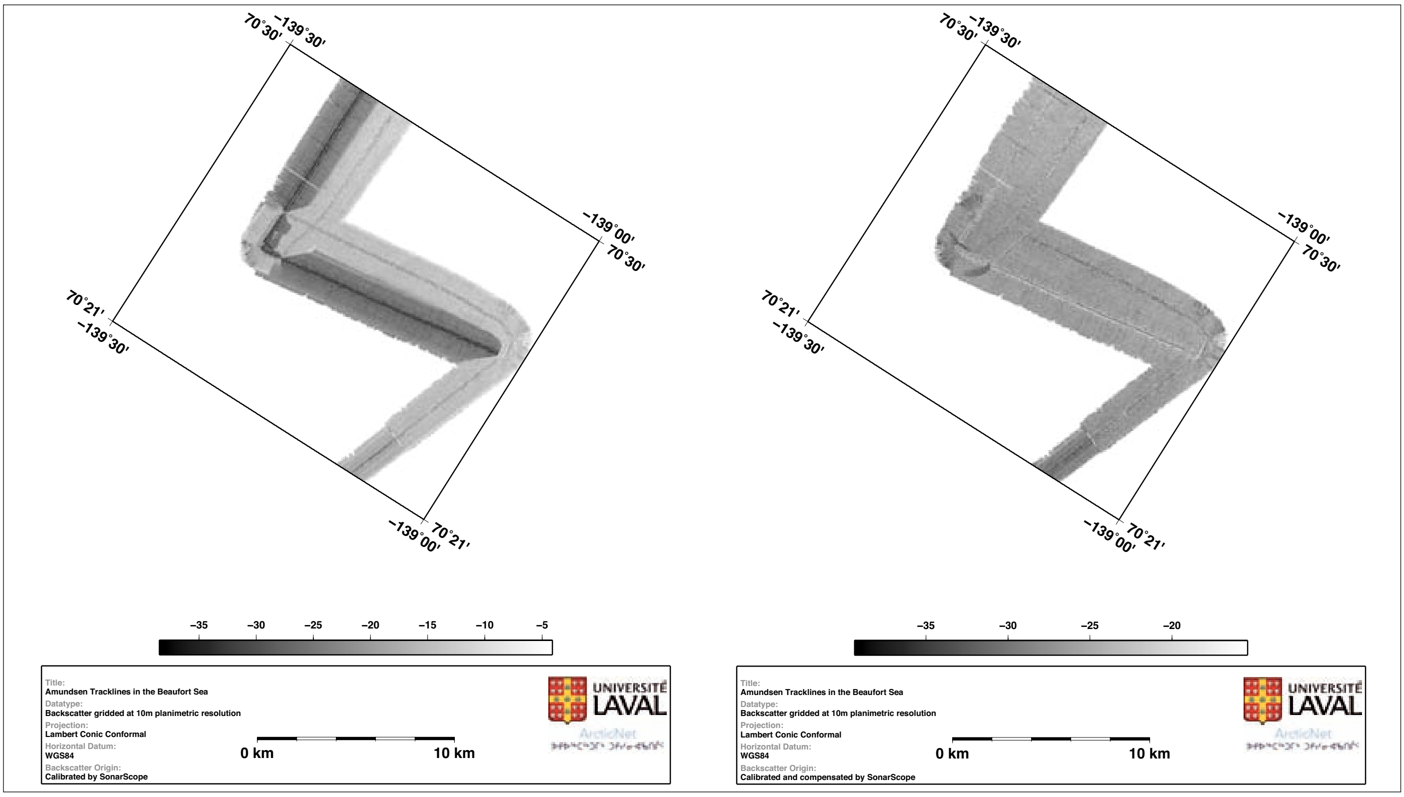

Fig. 7: Angular compensated BS mosaic following the transmission sector pattern calibration (a, left) and following a statistical compensation to remove the remaining 10 dB inter-line bias (b, right)

The modelling proved quite difficult given the poor quality of the real-time backscatter measurements. A much more successful approach, and one which is currently being investigated at IFREMER, is to use a BS model obtained from another calibrated echo sounder (single-beam or split-beam) mechanically steered at several transmission angles in order to obtain a more realistic BS angular response curve. Nevertheless, the calibration survey and subsequent analysis allowed for a substantial improvement in the precision of the mean BS value of the BS mosaics.

Compared to other multibeam echo sounders previously investigated by the author, the EM302 installed on CCGS »Amundsen« shows very strong transmission sector patterns modulations. Several attempts were made to find the causes of these modulations. During this investigation, it was discovered that some of the transmit channels of the EM302 are in a degraded state. However, the most plausible explanation is the fact that the EM302's transducers are encased behind a titanium enforced polymer protective window which is likely to affect the transmitted source level and sector patterns significantly more than for normal vessels. For operations in ice, this window is however essential to the protection of the transducers.

Conclusion

This project has focused on the application of a unique calibration procedure dedicated to the compensation of transmission sector patterns of multi-sector, multi-swath multibeam echo sounders. Uncalibrated transmission sector patterns modulate the backscatter response and are visible as intra-line artefacts. The calibration procedure was applied on backscatter data collected by CCGS »Amundsen«. The procedure included the successful conduct of a calibration survey in the Canadian Arctic and subsequent analysis of the backscatter data using the software SonarScope. The precision of the mean BS value of virtually all Transmission Modes is improved in the 15 to 60 degrees angular range. Residual sector boundary steps remained problematic and visible in the calibrated images, and overall, the calibration could be improved with better estimation of the parameters of the BS model. Indeed, due to the multibeam echo sounder's protective window deteriorating the raw backscatter measurements, the modelling of the BS from empirical data proved difficult.

Several investigations were carried out in order to identify the cause of a remaining inter-sector bias. This lead to the discovery of transmission channel problems. However, the cause of the bias was most likely due to a hardware software incompatibility. The fact that this problem did not lead to any discernible artefact on the bathymetry data highlights the fact that backscatter measurements are more sensitive to changes in system-dependent parameters.

Multibeam backscatter offers several applications in seabed classification, habitat mapping and seabed monitoring. These applications can potentially be very beneficial in fundamental sciences such as geology and benthic biology and ecology. Scientists wishing to make use of multibeam backscatter must however be fully aware of the limitations and pit-falls of multibeam echo sounder measurements. Most notably, the status of the instruments should be well understood, the context under which the data was collected and the processing applied prior to delivery should be well controlled. ⚓

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