Backscatter Adjustment for Multi-Sector Multi-Swath Multibeam Echosounders

Jean-Guy NISTAD

Key words: backscatter, multibeam echosounders, transmission patterns

SUMMARY

Many survey organizations whose primary focus is bathymetry simultaneously collect the co-registered backscatter from multibeam echosounders, more often than not in an opportunistic manner. While technological innovation and good survey practice have rendered bathymetric data collection more efficient and measurements both precise and accurate, so much cannot be said about backscatter data. Indeed, the sensitivity of the backscatter measurement cycle coupled with limited good survey guidelines leads to real-time backscatter measurements of poor quality requiring intensive post-processing efforts. While accurate geometric and environment compensations cannot be known until time of survey, an accurate system-dependent *a priori* compensation is possible by properly accounting for the transmit antenna sector pattern(s). Especially with multi-sector multibeam echosounders however, the transmit sector patterns can strongly modulate the backscatter response. This unwanted effect, inherent to the sensor characteristics, requires an appropriate compensation. A method to minimize this modulating effect has been developed at IFREMER (Brest, France). The method consists in conducting a field calibration survey, modeling or parameterizing the transmission sector patterns and injecting the results into the multibeam echosounder to produce real-time backscatter measurements devoid of system-dependent artefacts. This method was applied successfully on Kongsberg EM302 and EM710 multibeam echosounders. Results demonstrate a clear improvement in the precision of the backscatter measurements following application of the calibration even when the real-time uncorrected backscatter measurements are of very poor quality. However, the analysis also highlights the difficulty in obtaining consistently accurate results when no prior knowledge of the field calibration survey seabed substrate exists. Such prior knowledge obtained from an auxiliary calibrated echosounder offers considerable improvement potential.

1. INTRODUCTION

The availability in most modern multibeam echosounders (MBES) of co-registered backscatter data potentially indicative of the seabed's acoustic reflectivity property has certainly contributed to expand their use beyond traditional hydrographic users. Contrary to bathymetry measurements however, the lack of well-established standards, both from MBES manufacturers and users, and of good survey practice lead to backscatter measurement variability, affecting accuracy, precision and repeatability. Publication by the GeoHab Backscatter Working Group (BSWG) of the *Guidelines and Recommendations* document (Lurton & Lamarche, 2015) is a first milestone aimed at addressing these shortcomings.

Common recognizable problems with backscatter data include level biases between mosaics collected from multi-source and multi-platform datasets (Hugues Clarke *et al.*, 2008) and undesired level fluctuations visible when the MBES acquisition parameters are changed during a survey or when the MBES is inadvertently brought into saturation (Beaudoin *et al.*, 2014). Multi-sector, multi-swath multibeams[1] add yet another source of fluctuations often visible as along-track banding artefacts. The cause of this effect lies with the unique transmission directivity pattern (henceforth, *Tx pattern*) exhibited by each of the transmit antenna sector. Without proper real-time compensation of the Tx patterns, artefacts will be visible in all backscatter products. These artefacts are not easily corrected in post-processing using conventional correction methods such as angular normalization.

IFREMER (Brest, France) has developed a field calibration procedure (Augustin, 2013) which properly accounts for the Tx patterns of the transmit antenna. The procedure takes advantage of the capability of modern Kongsberg Maritime EM-series MBES to customize the parameters of the real-time compensation. Once the calibration is properly completed, the MBES will be able to deliver real-time backscatter devoid of any modulation effects from the sector Tx patterns.

This paper presents preliminary results of the Tx pattern field calibration applied to EM302 and EM710 MBES operated by several independent organizations. This serves to illustrate the variability of real-time backscatter measurements and to validate the generalized applicability of the field calibration method. Across the various organizations, significant improvements in measurement precision have been obtained, but further improvements are still necessary in order to obtain 'absolute calibrated' measurements.

2. RAW BACKSCATTER MEASUREMENT QUALITY

Figure 1 to Figure 4 illustrate several examples of digital terrain models and Backscatter Strength (BS) mosaics from EM302 and EM710 multi-sector MBES collected by various organizations. These example datasets were collected on board different ships, using different MBES, under independent survey conditions and in depths ranging from 20 meters to more than 2000 meters. The BS mosaics have been gridded in the software SonarScope® (Augustin & Lurton, 2005) following import of the raw 'all' files which contain the Kongsberg 'Seabed image' EM-datagram (Kongsberg, 2015). By definition, the backscatter data is thus acquired through the Kongsberg standard backscatter data reduction process and represents a best-estimate of the seabed reflectivity.

[1] Use of the term multi-swath shall be discarded in the rest of this paper as any *swath* always consists of one or more *sectors*.

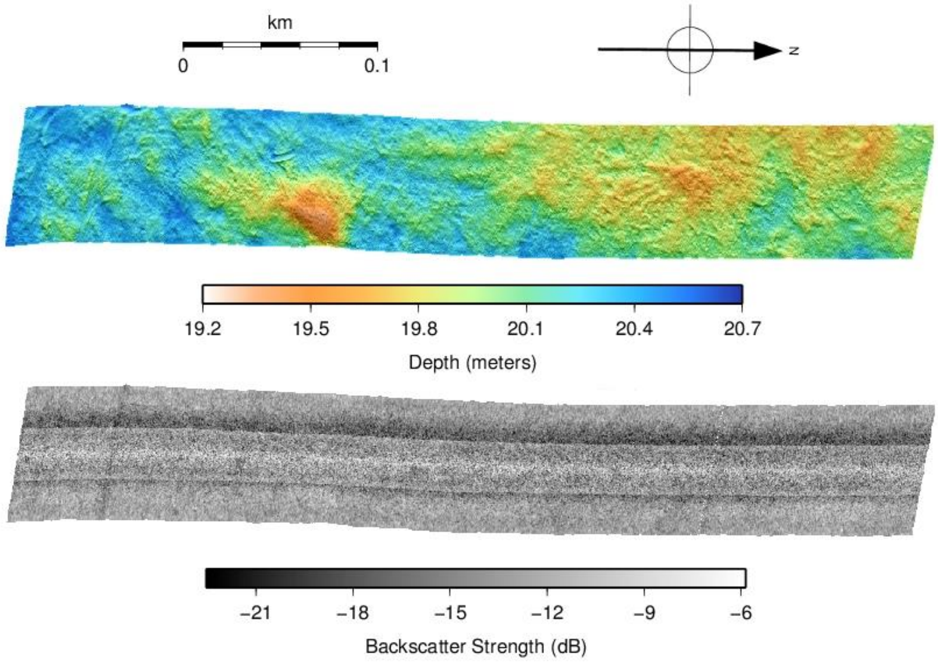

Figure 1: Digital terrain model and backscatter mosaic from EM710 data collected by the French Hydrographic Service (SHOM) on board the survey ship BH2 *La Pérouse*. The spatial resolution of the projected grids is 0.25 m.

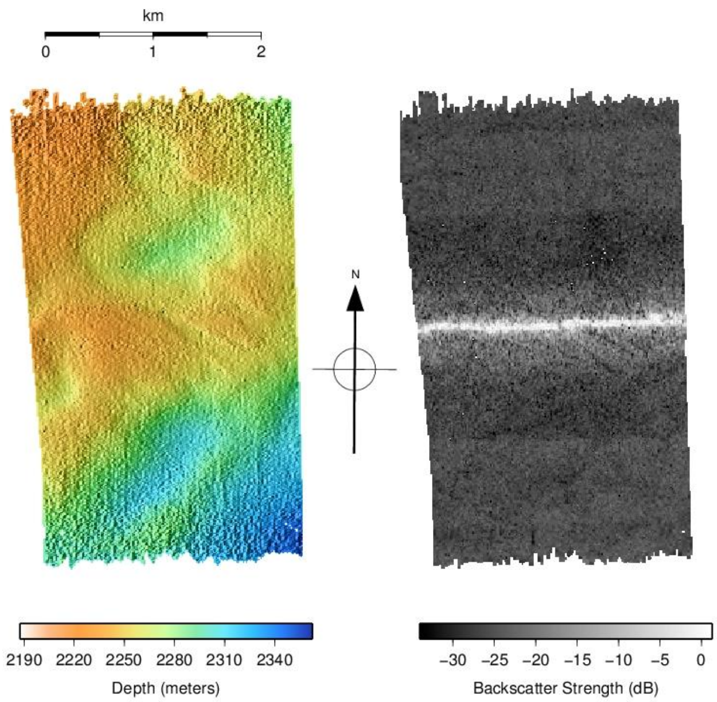

Figure 2: Digital terrain model and backscatter mosaic from EM302 data collected by the Ocean Exploration Trust (OET) on board the exploration ship E/V *Nautilus*. The spatial resolution of the projected grids is 20 m.

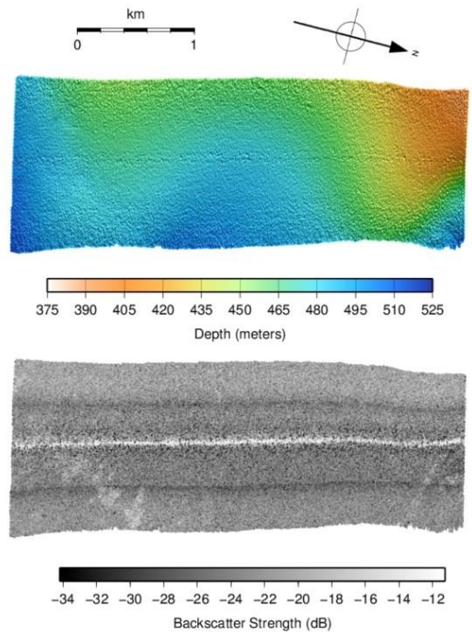

Figure 3: Digital terrain model and backscatter mosaic from EM302 data collected by NIWA on board the research vessel RV *Tangaroa*. The spatial resolution of the projected grids is 10 m.

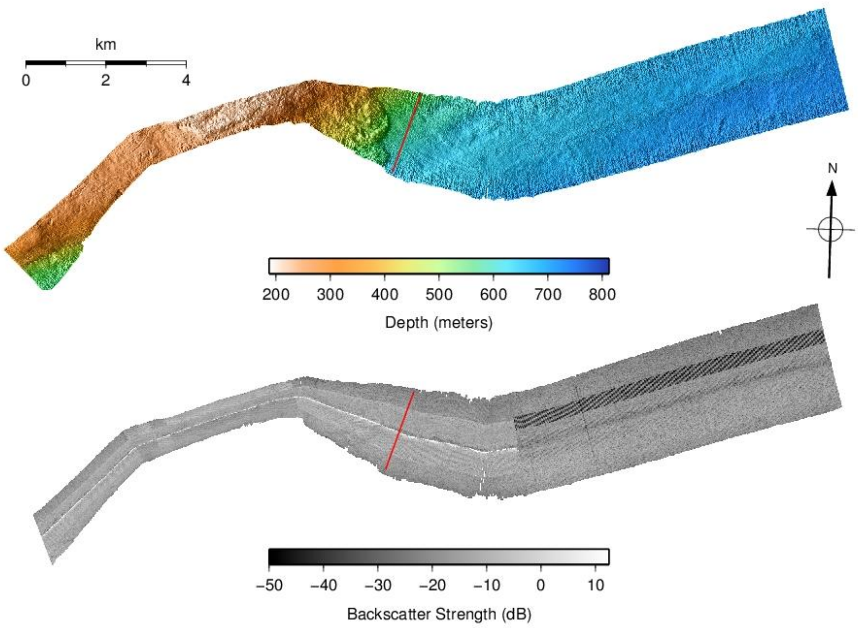

Figure 4: Digital terrain model and backscatter mosaic from EM302 data collected by ArcticNet on board the scientific ice-breaker CCGS *Amundsen*. The spatial resolution of the projected grids is 10 m. A red line separates two contiguous data files.

While the digital terrain models all meet the accuracy requirements of the respective organizations, the BS mosaics clearly present some modulating effects visible as along-track banding artefacts. For consistency, all mosaic contrasts have been enhanced to the 0.5% quartile. The extent of the modulation varies, with the E/V *Nautilus* EM302 presenting the least amount of modulation (although this is probably due to an increased dynamics of the gray-level scale caused by the very high specular level).

The modulating effect on the BS mosaics can be easily correlated to changes in operational parameters of the MBES. Figure 5 clearly identifies this correlation with corresponding changes in the Depth Mode parameter of the CCGS *Amunden* EM302 as the MBES toggles between *Shallow* (2), *Medium* (3) and *Deep* (4) modes. Although not evidenced in Figure 5, changes to two other parameters, the Swath Type and the Pulse Type, are also susceptible to modulate the backscatter measurements. The Depth Mode, Swath Type and Pulse Type shall be referred collectively in this paper as *Transmission Modes*. With the exception of the ArcticNet dataset, all of the dataset examples from Figure 1 to Figure 4 were collected in a single transmission mode. Table 1 summarizes the effective transmission modes used.

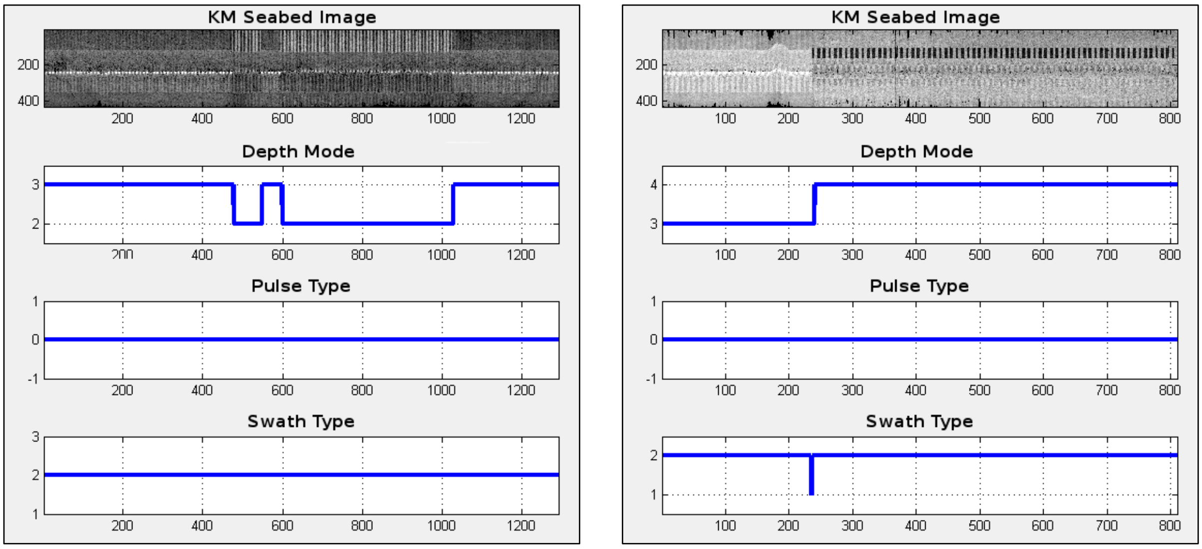

Figure 5: Effect of changes in Depth Mode for the two contiguous survey lines of Figure 4.

Table 1: Transmission modes used in the example datasets of Figure 1 to Figure 4

	Depth Mode	**Swath Type**	**Pulse Type**
Figure 1 – SHOM dataset	*Very Shallow*	*Single*	*CW*
Figure 2 – OET dataset	*Deep*	*Single*	*CW*
Figure 3 – NIWA dataset	*Medium*	*Single*	*CW*
Figure 4 – ArcticNet dataset	*Shallow*	*Dual*	*CW*
	Medium	*Dual*	*CW*
	Deep	*Dual*	*CW*

3. TRANSMISSION MODES

Figure 6 depicts the sector Tx patterns of an EM302 echosounder operating in the transmission mode characterized by the *Medium* Depth Mode, *Single* Swath Type and *CW* Pulse Type. The EM302 *Medium* Depth Mode is comprised of four sectors, each transmitting in a specified sequence within a complete ping cycle and at a specific frequency. Originally developed to focus the available transmit power in specific angular sectors in order to achieve greater range, sector transmission (and Tx and Rx beamforming) also improve survey sounding density and homogeneity by allowing for real-time motion stabilization in roll (at the receive antenna), pitch and yaw (at the transmit antenna). They also optimize the survey parameters by automatically adjusting the Pulse Type from continuous wave (*CW*) to frequency modulation (*FM*) and pulse characteristics (pulse length in the case of *CW*) according to range requirements. The detailed shape of the sector Tx patterns will depend on several factors some of which with varying time-scales:

- **The transmit frequency**
  The beam width of the Tx pattern is directly proportional to the signal wavelength.
- **The transmit antenna sector steering**
  Sector steering will result in an increased beam width by $1/\cos(\theta_s)$, where θ_s is the sector steering angle, and in a deformation as the Tx pattern wraps into a conic shape.
- **The physical state of the transmit antenna at production**
  The unique dimensions and elementary transducer elements of the antenna unit create distinctive Tx patterns.

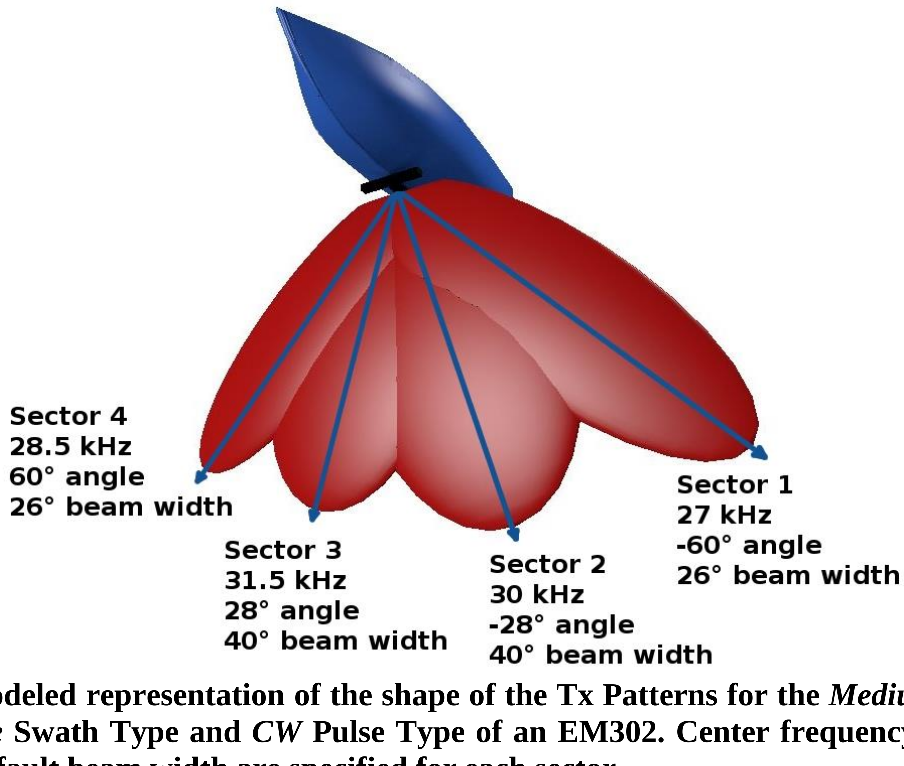

Figure 6: Modeled representation of the shape of the Tx Patterns for the *Medium* Depth Mode, *Single* Swath Type and *CW* Pulse Type of an EM302. Center frequency, default angle and default beam width are specified for each sector.

- **The mounting of the transmit antenna on the ship**
  The hull structure and the MBES mounting apparatus may affect the shape of the Tx patterns in a non-trivial way.
- **The aging of the transmit antenna**
  As the antenna components age (e.g. broken ceramics, dead channels, biofouling), the Tx patterns also change.

4. THE NEED FOR MULTIBEAM CALIBRATION

Calibrated echosounders attempt to improve backscatter measurements by accounting for the undesirable system-dependent contributions. Such calibrated systems provide more stable and accurate measurements which lead the way towards calibrated backscatter data suitable for quantitative analysis (Lurton & Lamarche, 2011). Backscatter calibrations are conventionally performed in controlled environments (Lanzoni & Weber, 2010). However, for practical purposes, field calibration procedures are much more suitable; especially for medium-depth to deep-depth MBES since the necessary range requirements exclude them from laboratory calibration. Also, field calibrations allow capturing the multibeam specific system-dependent effects after final instrument setup and allow for controlled re-calibration according to requirements.

Although not encompassing all of the system-dependent effects, the Tx pattern modulation is a significant contributor to the overall system-dependent effects. As such, it strongly modulates the Backscatter Strength (BS) otherwise used as a proxy to the geological seabed facies. The inherent difficulty involves precisely the separation of the physical contribution of the seabed from the system-dependent contribution of the Tx patterns. Multi-sector MBES

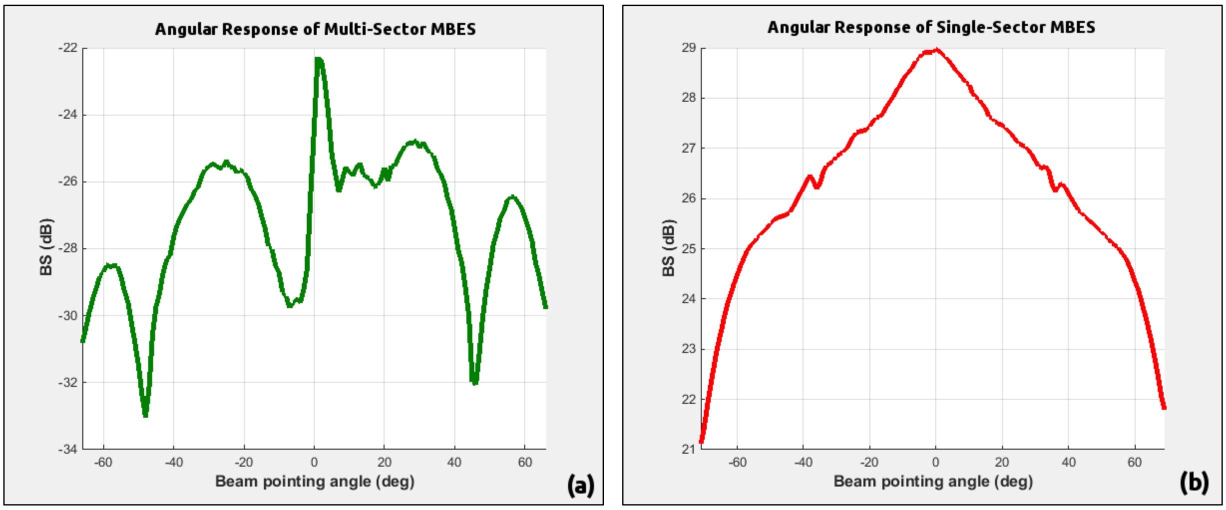

Figure 7: Combined BS and Tx pattern angular response curves for a multi-sector (a) and single-sector (b) MBES. In (a), the Tx patterns of four sectors are clearly superimposed on the BS angular response. In (b), the distinction between the Tx pattern and BS angular responses cannot be made.

offer an advantage over single-sector MBES in that the characteristic angular dependence of the Tx patterns of the transmit antenna is noticeably different from the BS angular dependence. Its signature can thus more easily be identified in the uncompensated backscatter data (Figure 7a). This is in contrast to single-sector MBES where the angular responses of the Tx pattern and the BS exhibit a similar dependence which makes their separation very difficult (Figure 7b), even though the Tx pattern angular dependence for single-sector MBES is usually simpler and predictable.

5. TX PATTERN CALIBRATION PROCEDURE

5.1. Underlying Principle

The objective of the Tx pattern field calibration procedure is to determine the parameters that will optimize the compensation of the sector Tx patterns of an EM-series multi-sector MBES. For these specific MBES, the compensation is controlled by the parameter values set in a dedicated bscorr.txt file located in the Processing Unit (PU). Any change in values will result in a change of the real-time compensation of the sector Tx patterns. Figure 8 schematizes the four-step working principle of the procedure.

Survey data recorded in a specific transmission mode is first collected using the previous bscorr.txt file. The 'Seabed image' EM-datagram collected is acquired through the Kongsberg standard backscatter data reduction process. Therefore, real-time compensations for both the BS angular dependence and the Tx patterns have been applied. The survey data must have been collected over a flat seabed with homogeneous geological facies. This is an important criterion for two main reasons. First, the Tx patterns are dependent on the *beam pointing angle*[2] while the BS is dependent on the *seafloor incidence angle*. Only under the latter criterion can both angles be considered approximately identical. Second, the generic shape of the BS angular response is often reasonably predictable under the same criterion. Several known BS models exists: e.g. the Generic Seafloor Acoustic Backscatter (GSAB) model (Lamarche *et al.*, 2011) is used in SonarScope® and will be applied here. Optimization techniques (e.g. Simplex and Newton) are used on the survey data to estimate the BS model parameters thus giving access to the Tx patterns.

The first step of the procedure consists in removing the real-time BS compensation and in the second step, in estimating the parameters of the GSAB model from the uncompensated dataset. In the third step, the modeled BS is applied to the dataset as an alternate more realistic compensation for the BS angular dependence. In this step, the real-time Tx pattern compensation associated with the previous bscorr.txt file is also removed. The residuals represent the Tx sector patterns. Similar to the modeling of the BS angular dependence, the Tx pattern functions which are ideally *sinc* (cardinal sine) functions have to be modeled. Thus, step four consists in estimating the parameters of the Tx pattern models and exporting the results into a new bscorr.txt file. This file is then fed back into the PU, thus enabling all

[2] The *beam pointing angle* is defined as the angle between a beam *Maximum response angle* and the vertical axis of the ship reference frame. It is relative to the receive antenna but can be related to the transmit antenna using their known mounting angles.

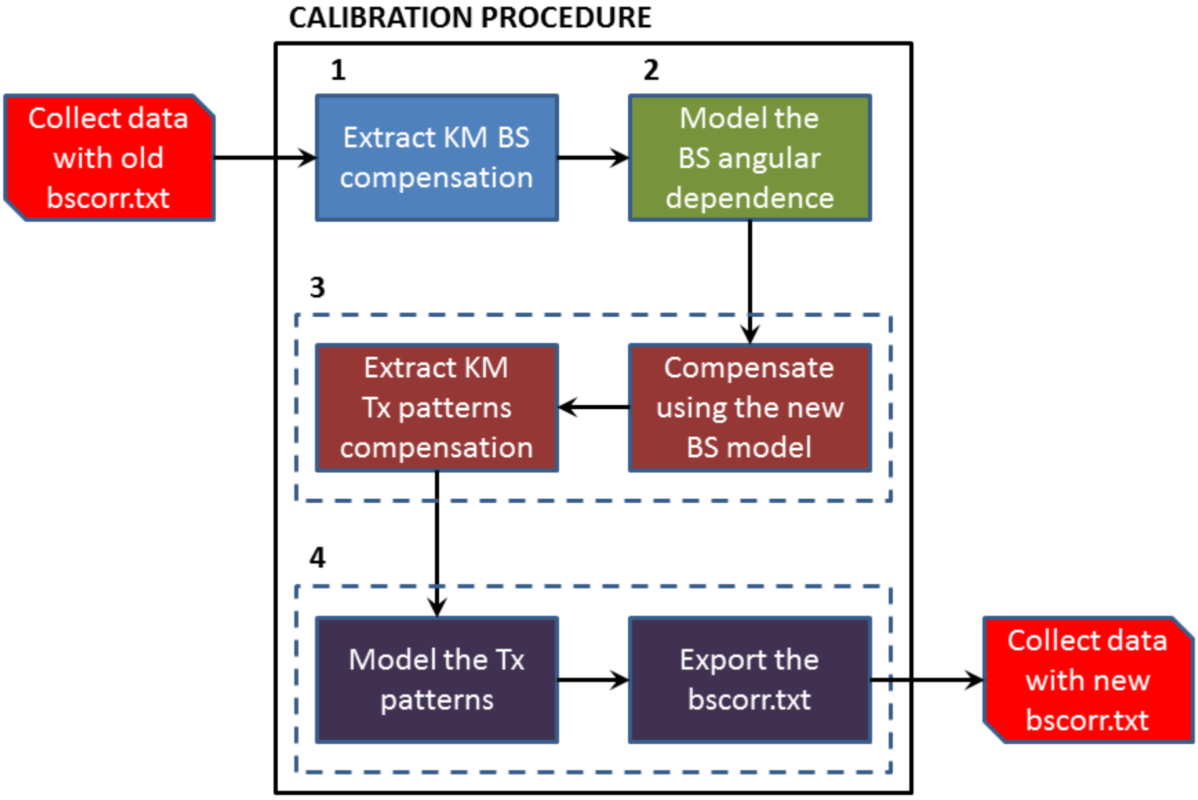

Figure 8: Tx Pattern Calibration Procedure Workflow

subsequent survey data in the particular transmission mode to be devoid of sector Tx pattern modulations. Apart from the modeling of the BS angular dependence, the whole procedure must be repeated for each transmission mode used by the MBES, i.e. every unique combination of Depth Mode, Swath Type and Pulse Type. For the EM302, this can potentially result in 14 individual datasets upon which the procedure must be repeated.

A fundamental difference exists between EM302 and EM710 datasets in regards to how the Tx patterns are modeled and parameterized for storage in the bscorr.txt file. For the EM302, the Tx patterns are modeled as polynomial approximations of the Tx radiation lobe shape, with three variables needing to be estimated:

- The sector source level;
- The sector angle;
- The sector beam width.

For the EM710, a collection of nodes defining a coordinate pair (angle, level) is used instead. The estimation consists in finding the parameters of a constrained spline function for a collection of maximum 32 nodes per sector. The next section presents results obtained using both modeling methods.

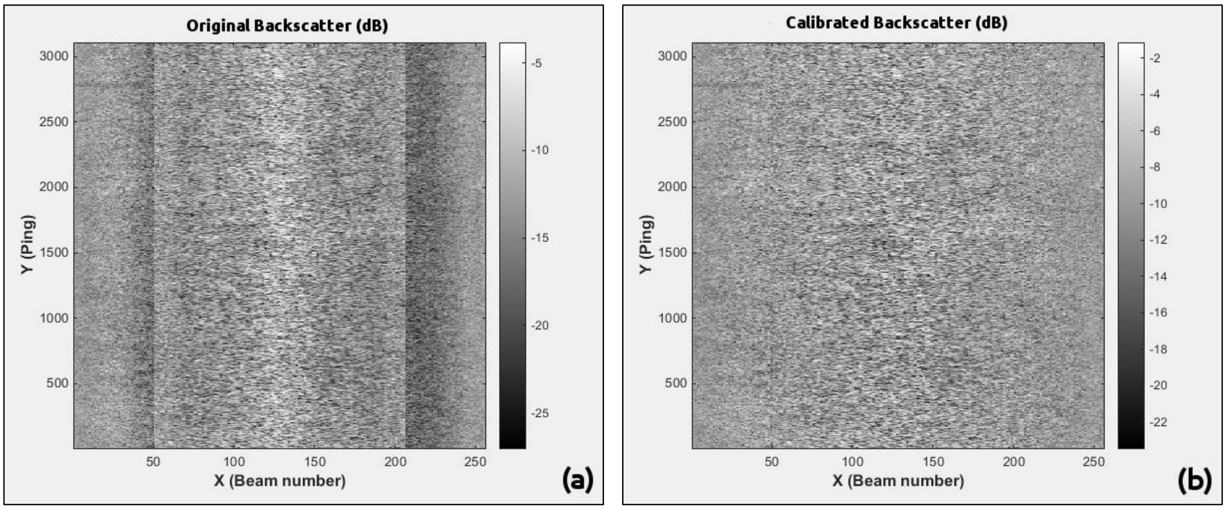

Figure 9: Original (a) and calibrated (b) backscatter images in ping vs beam geometry from the SHOM dataset (EM710 example). Both images are compensated for the BS angular response and the Tx patterns.

5.2. Experimental Results and Observations

The Tx pattern field calibration was applied on the SHOM EM710 dataset. Figure 9 and Figure 10 respectively compare the backscatter data before and after application of the calibration procedure for the *Very Shallow* Depth Mode, *Single* Swath Type, *CW* Pulse Type. Figure 9 shows the backscatter images of the complete survey-line in ping-versus-beam geometry. Both images are compensated for the BS angular response and the Tx patterns: Figure 9a using the KM real-time compensations; Figure 9b using the BS and Tx pattern models resulting from the calibration.

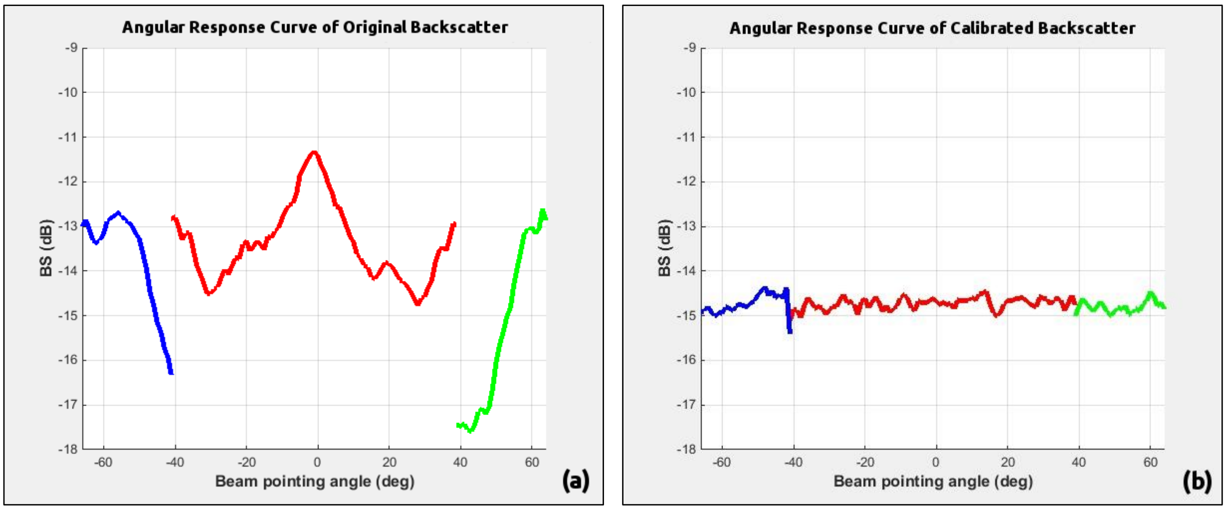

Figure 10: Angular response curves color-coded per sector of the original (a) and calibrated (b) backscatter images of Figure 9.

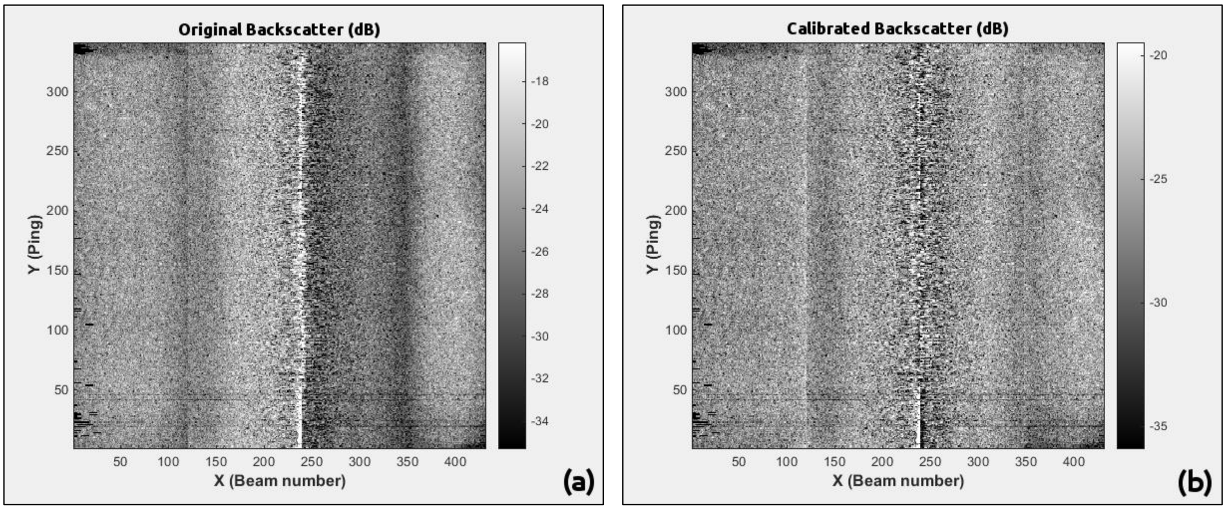

Figure 11: Original (a) and calibrated (b) backscatter images in ping vs beam geometry from the ArcticNet dataset (EM302 example). Both images are compensated for the BS angular response and the Tx patterns.

Overall, there is a definite improvement in the precision of the calibrated result. The angular response in Figure 10a shows an intensity range of 7 dB while in Figure 10b the range does not exceed 1 dB, well within the 2 to 3 dB range suitable for robust seabed type discrimination (Lurton & Lamarche, 2015). One important point to mention is that the near-incidence component of the BS compensation is not applied on the original dataset. Therefore, angles within [-15° +15°] (cross-over angles between the near-incidence and oblique incidence for the EM710) should actually not be considered.

A second set of results involves the ArcticNet EM302 dataset for the *Shallow* Depth Mode, *Single* Swath Type, *CW* Pulse Type. This time, the range improvement is somewhat less satisfying: from 10 dB to 4.5 dB. Similar to the case of the EM710, the near-oblique

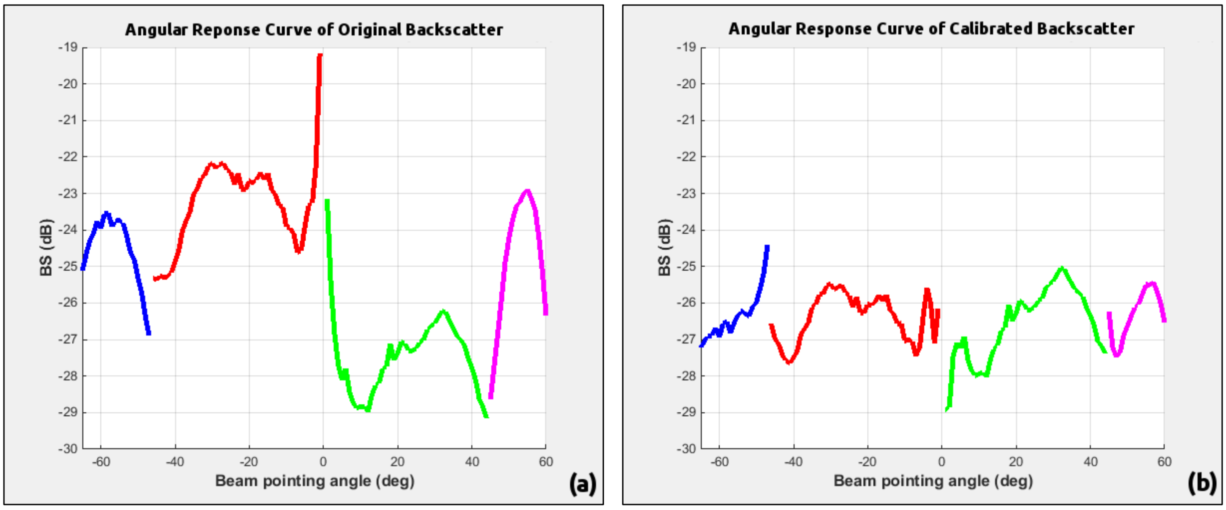

Figure 12: Angular response curves color-coded per sector of the original (a) and calibrated (b) backscatter images of Figure 11.

incidence is not compensated on the original backscatter image. Angles within [-6° +6°] (cross-over angles between the near-incidence and oblique-incidence for the EM302) should thus be excluded. In the calibrated dataset, sector boundaries remain problematic and fluctuations in excess of 3 dB are still present within individual sectors (Figure 12b).

Comparison of the two datasets highlights the inherent difficulties in estimating the polynomial model parameters in the EM302. In comparison, the spline function approach of the EM710 offers much more flexibility in adjusting itself to the empirical Tx pattern data.

6. SOURCES OF DIFFICULTIES AND FURTHER IMPROVEMENTS

Accurately modeling the BS angular response is the crucial step of the Tx pattern calibration method. Any deviation between the real and modeled BS will propagate into the modeling of the Tx patterns and their compensations. In this situation, one would obtain good results over the calibration survey area (as in Figure 9b), but when new survey data is collected using the new Tx pattern compensations over another geological facies, residual along-track banding artefacts are likely to be visible.

In the Tx pattern calibration, several transmission modes are normally used over the survey area. These multiple datasets certainly improve the statistical confidence in the survey area's BS response since the latter should in theory be identical regardless of the transmission mode. However, practice has shown that determining a BS model over several transmission modes may not be as trivial. Figure 13a illustrates this difficulty with the overlay of the BS angular responses of four individually color-coded transmission modes from the ArcticNet dataset:

- *Shallow* Depth Mode, *Single* Swath Type, *CW* Pulse Type;
- *Shallow* Depth Mode, *Dual* Swath Type, *CW* Pulse Type;

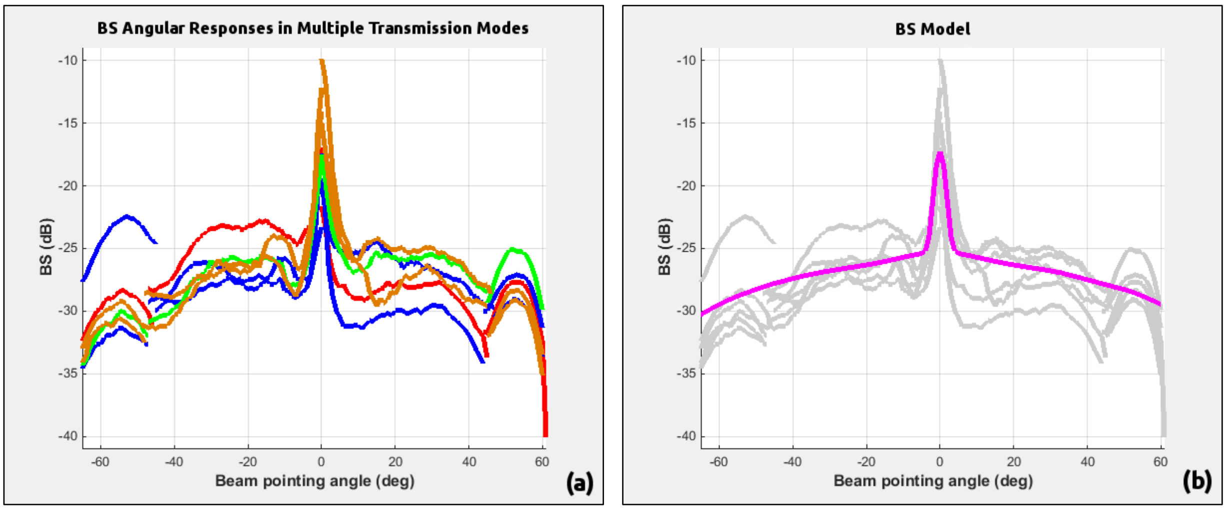

Figure 13: Four overlaid BS angular responses collected over the same seabed, color-coded per transmission mode (a). Estimated BS model (magenta curve) overlaid on the same BS angular responses (b). Dataset from ArcticNet.

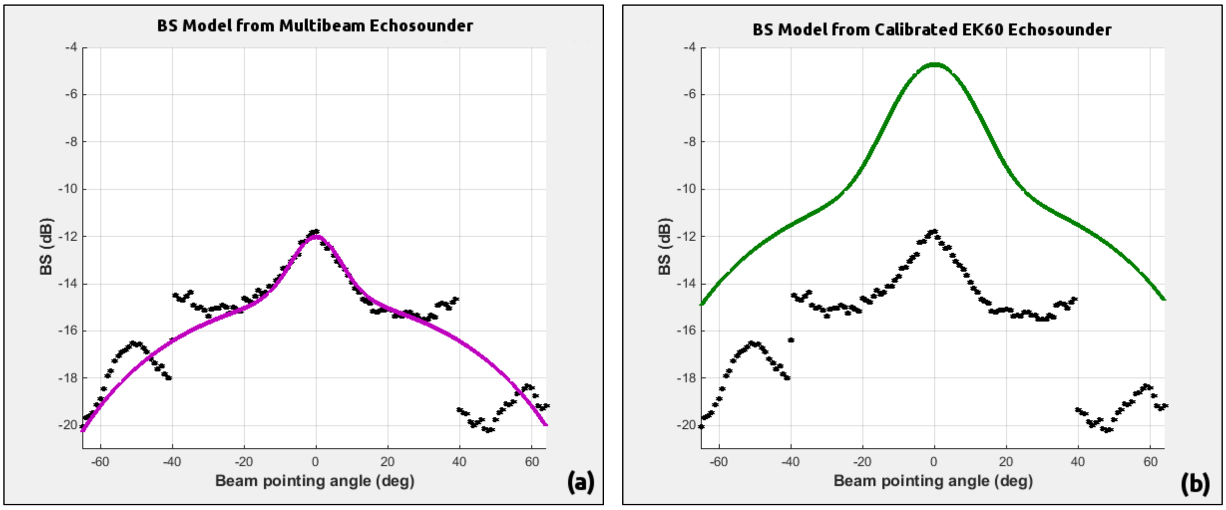

Figure 14: BS model estimated from MBES data (a) and from a calibrated EK60 echosounder (b). MBES dataset from SHOM; EK60 data from IFREMER.

- *Medium* Depth Mode, *Single* Swath Type, *CW* Pulse Type;
- *Medium* Depth Mode, *Dual* Swath Type , *CW* Pulse Type.

Clearly, it is not trivial how to estimate the parameters of a common BS model within this dataset. Should the mean of all curves be considered (as is done in Figure 13b)? Or should the 'best-looking' curve be chosen? Evidently, the greater the variability in the backscatter levels due to a mismatch between the real-time Tx pattern compensations and the true Tx patterns, the greater the difficulty in estimating the BS model. However, other factors are also accounting for variations in the backscatter levels. These include:

- The slight sector center frequency offset;
- The different pulse types and pulse characteristics;
- The unique real-time sector steering in each survey-line.

The assumption made as to the shape of the BS angular dependence from the collected data itself thus implies a certain amount of subjectivity. However, if the BS angular response were provided through an external means, such as an auxiliary calibrated echosounder, this problem would not arise. Figure 14 provides a first-order illustration of this. Figure 14a shows the BS model estimated from the MBES data in the SHOM dataset example (Figure 9 and Figure 10). Figure 14b shows the BS model obtained from a calibrated EK60 split-beam echosounder over the same survey area (Eleftherakis *et al.*, 2015). Both the shape and the mean value of the BS angular response are clearly different. However, the center frequencies of both instruments are different: the EM710 has a center frequency of 85 kHz (bandwidth from 73 to 97 kHz) while the EK60 data was collected using a center frequency of 300 kHz. Therefore, the EK60-derived BS model should not be used in the 85 kHz Tx pattern calibration due to this frequency difference. However, this exercise highlights the improvements potentially achievable using 'inter-calibration', i.e. obtaining a modeled BS from another independently calibrated echosounder. A practical inter-calibration solution would then be to define a calibration reference zone where BS models for a set of different frequencies have been determined *a priori*, hence avoiding the hypothesis made on the seafloor response as discussed above. The reliability of the Tx pattern calibration solution would be consequently greatly improved.

7. CONCLUSION

MBES datasets obtained from various origins have demonstrated that real-time backscatter measurements present artefacts at the survey-line level. These artefacts take the form of along-track bands and have been correlated to the inaccurate compensation of transmit sector patterns. These incorrect compensations result in a modulation of the backscatter response. Unique to multi-sector multi-swath multibeams, this problem poses significant challenges to the production of backscatter products.

A field calibration procedure has been proposed which aims at more accurately determining the true parameters of the sector directivity pattern compensations. Successfully completing this procedure allows all further backscatter data collected to be devoid of such modulation effects or at the least to be very much reduced. The modeling approach is somewhat different between EM302 and EM710 echosounders.

The principle limitation of the procedure is the difficulty in properly estimating the BS angular dependence on the calibration survey area. Comparison with the BS angular dependence calculated from measurements of a calibrated echosounder highlights this limitation and points towards a modified procedure where an external estimate of the BS angular dependence is required.

REFERENCES

AUGUSTIN, J.M.; LURTON, X. (2005): *Image amplitude calibration and processing for seafloor mapping sonars,* in Proceedings of the Europe Oceans 2005, IEEE, pp. 698–701.

AUGUSTIN, J.M. (2013): *E/V Nautilus - Sea trials - April 2013 - Backscatter analysis and Tx sector compensation for EM 302*, technical report, Ifremer AS-2013-28.

BEAUDOIN, J.; REIS, T.; DOUCET, M. (2014): *Recent Improvements to Seafloor Imagery Acquisition and Processing Procedures for R2Sonic Multibeam Echosounders*, in Proceedings of the 2014 Canadian Hydrographic Conference, St-John, Newfoundland, Canada.

ELEFTHERAKIS, D.; AUGUSTIN, J.M.; BERGER, L.; LE BOUFFANT, N.; LOYER, S.; LURTON, X.; PACAULT, A.; VRIGNAUD, C. (2015): *Collection, processing and interpretation of seafloor backscatter from various coastal seabed types using a high- & multi-frequency multibeam echosounder*, Shallow Survey 2015, Plymouth, UK.

HUGUES CLARKE, J. E.; IWANOWSKA, K. K.; PARROTT, R.; DUFFY, G.; LAMPLUGH, M.; GRIFFIN, J. (2008): *Inter-calibrating multi-source, multi-platform backscatter data sets to assist in compiling regional sediment type maps: Bay of Fundy*, in Proceedings of the 2008 Canadian Hydrographic Conference and National Surveyors Conference, Victoria, Canada.

KONGSBERG (2015): *Kongsberg EM Series Multibeam echo sounder EM datagram formats*, Instruction Manual, 850-160692/U, 130 p.

LAMARCHE, G.; LURTON, X.; VERDIER, A.L.; AUGUSTIN, J.M. (2011): *Quantitative characterisation of seafloor substrate and bedforms using advanced processing of multibeam backscatter - Application to Cook Strait, New Zealand*, Continental Shelf Research, 31, 2, 93-109.

LANZONI, J.; WEBER, T. C. (2010): *High-resolution calibration of a multibeam echo sounder*, in Oceans 2010 MTS/IEEE Seattle, p. 1-7.

LURTON, X.; LAMARCHE, G. (Eds) (2015): *Backscatter measurements by seafloor mapping sonars. Guidelines and Recommendations*. 200 p.
http://geohab.org/wp-content/uploads/2013/02/BWSG-REPORT-MAY2015.pdf

BIOGRAPHICAL NOTES

Following the completion of a FIG/IHO Cat. A Certification at the HafenCity University Hamburg, Jean-Guy Nistad joined the Federal Maritime and Hydrographic Agency (BSH) in Rostock, Germany, as Hydrographic Engineer. Prior to his time in Germany, he completed both an electrical engineering and a geomatics degree in Canada. He then worked six years for CIDCO, the *Interdisciplinary Centre for the Development of Ocean Mapping* in Canada. In 2014 and 2015, he collaborated with Laval University and the ArcticNet network in Canada in order to oversee swath bathymetry and backscatter data collection in the Canadian Arctic. This experience led him to further investigate the topic of multibeam backscatter calibration with IFREMER, the *French Research Institute for Exploitation of the Sea*.

ACKNOWLEDGEMENTS

A special Thank You goes to Mr. Jean-Marie Augustin and Mr. Xavier Lurton for their input and many contributing remarks to the writing of this paper.

The following organizations have gratefully accepted to provide datasets for analysis:

- ArcticNet and Laval University (Canada)
- Service Hydrographique et Océanographique de la Marine (France)
- Ocean Exploration Trust (USA)
- National Institute of Water and Atmospheric Research (New Zealand)

CONTACTS

Jean-Guy Nistad
German Federal Maritime and Hydrographic Agency (BSH)
Neptunallee 5
18057 Rostock
Germany
Tel. +49 (0)381 4563-5
Fax + 49 (0)381 4563-948
Email: jean-guy.nistad@bsh.de
Web site: http://www.bsh.de

Jean-Marie Augustin
IFREMER
Centre Bretagne - ZI de la Pointe du Diable
CS 10070 - 29280 Plouzané
France

Xavier Lurton
IFREMER
Centre Bretagne - ZI de la Pointe du Diable
CS 10070 - 29280 Plouzané
France

Patrick Lajeunesse
Département de Géographie
Pavillon Abitibi-Price
2405, rue de la Terrasse, local 3113
Québec (Québec) G1V 0A6
Canada