MULTIBEAM ECHOSOUNDER CALIBRATION FOR BACKSCATTER MEASUREMENTS ON SEAFLOOR SURVEYS: DEFINITION OF NATURAL REFERENCE AREAS

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1 Introduction

The increasing importance of seabed backscatter in seafloor-mapping[1] raises the issue of calibration of seafloor-survey dedicated sonars (mainly multibeam echosounders or MBES) used for seafloor backscatter intensity measurement. A complete methodology has been defined and improved over the years regarding the calibration of sonar data with respect to bathymetric soundings, responding to needs of the hydrographic community[2]; however far less attention and effort has been given to intensity measurements. The main issues regarding seafloor backscatter measurement and calibration have been recently discussed in a collective report[1]. Several calibration methods can be considered for MBES; the most promising one (and possibly the only one practical) is backscatter measurement under operational conditions over reference areas showing a predictable backscatter level. The purpose of this paper is first to define the requirements of natural reference areas for swath sonar intensity calibration; and in a second step to present the first results of a project aimed at defining and validating some shallow-water areas for this purpose.

2 Rationale

Several approaches of intensity calibration can be considered for multibeam echosounders. A first straightforward idea is that the calibration should come directly from the constructors, ideally mastering perfectly all the characteristics of the various components of the sonar in terms of signal amplitude response; the combination of all elements should be used for retrieving the response of the complete instrument. While this could be feasible regarding strictly the electronic modules of the sonar, it is more difficult to apply to electro-acoustic transducers, especially after these have been installed on an operational platform such as a ship or underwater vehicle. A second solution consists in measuring the response of a complete system considered successively in transmission and in reception. Unfortunately this method, while applicable for high-frequency, compact and portable systems in a test tank, is not realistic for systems already installed on their platform.

Therefore the most practical solutions are calibration techniques applicable to the complete instrument in operational situation. Echo amplitudes measured from known and controlled targets can be compared to their expected values; the difference is used to retrieve the bias caused by the sensor. Such a method is standard for single-beam echosounders (SBES) used in fisheries acoustics[3, 4]; consisting of recording the sonar response from a reference point target located at controlled ranges and angles. The target is a full-metal sphere, with a diameter adapted to the signal frequency, and has to be moved inside the main lobe of the SBES and carefully positioned in order to measure the directivity pattern – including the response in the lobe axis, giving the nominal sensitivity. This approach has been adapted to MBES[5] and applied experimentally in some cases. However its routine application raises several operational issues: measuring at sea hundreds of very narrow beams (typically 1° and less) over a wide aperture (typically 150° across-ship) is not practical, while accurate target positioning inside the beams raises specific problems.

Hence the best method applicable today could be *in situ* calibration on natural reference areas with known backscatter characteristics. The advantages of calibration on such areas are many. Measuring the complete system response has a great advantage: this is done over a target similar to the ones to be met under operation conditions, and the characteristics of the sonar upon calibration account for the specific installation environment. Moreover it can be conducted swiftly, and hence impacts little on the operation schedule of a survey cruise; it can be either integrated inside the bathymetry calibration operations, or conducted independently.

This technique is commonly used by space-borne radars mapping the Earth's surface from satellites, for which direct measurements on the electronics or the arrays are obviously very difficult once deployed. These instruments are currently calibrated over stable areas of known backscatter strength, and therefore sufficiently predictable. The South American rainforest fulfils optimally the requirements of this approach[6]: the tree canopy shows a backscatter response with little dependence on incident angle, and is very stable over the seasons. Its characteristics make possible a calibration accuracy of a few tenths of dB. The experience gained in this field will be very beneficial to our approach.

3 Reference areas for backscatter-measuring systems

The choice of a natural reference area dedicated to backscatter measurement calibration implies a number of conditions. The main general requirement is stability and regularity; obviously a reference area should be as predictable and reliable as possible. Stability of the seafloor over time is paramount in order to minimize the risks of uncontrolled changes in the characteristics of the area. Strictly speaking, this may be unattainable, especially in shallow water, as several causes must be expected that could modify the local characteristics, either natural (storms, tides, currents, biological activity) or anthropogenic ones (such as trawling, dredging and anchoring).

Regarding the physical characteristics of a backscatter reference area, the topography should be as flat and regular as possible, in order to avoid the slope dependence caused by the relief features. Also the seabed characteristics should be homogeneous over the area. This should prevent any potential problem linked to the geometrical configuration of the survey lines dedicated to backscatter calibration. Clearly the backscatter level is also expected to show a simple and smooth behaviour with angle, minimizing particular phenomena such as specular reflection or azimuth dependence (linked to polarized roughness of the interface, such as tide-current ripples).

From a practical point of view, with respect to seagoing operations, a reference area should have dimensions compatible with the typical coverage of MBES, again to minimize any causes of errors linked to the survey geometrical configuration. Obviously it has to be easily accessible by survey ships; and ideally it should overlap with areas already defined for bathymetry measurement calibration. Note that a backscatter reference area fulfilling all the above conditions should be intrinsically a good candidate for becoming a bathymetry-reference as well. Most importantly, the local backscatter must be accurately measured using a reference sensor, which may be either a single- or multi-beam echosounder, previously calibrated, and working at a relevant frequency. A practical solution is to use a calibrated fisheries SBES, steered in order to insonify the seafloor at one (or several) intermediate oblique angle(s). Finally, regular surveys of the area must be conducted to check its stability and to apply possible corrections.

4 First design and evaluation of coastal reference areas

A project has recently been started, in the context of the Backscatter Working Group[1], with partners from France, Belgium and UK. All partners had actually already defined candidate sites for shallow-water reference areas close to their harbour facilities.

4.1 Description of the reference areas

4.1.1 Carré Renard and Pierres Noires (France)

Several reference areas have already been defined, in the Brest region, by SHOM in order to conveniently calibrate the hydrographic sonars operated on their survey vessels and launches. Among several close areas – specified for various aspects of the hydrographic calibration operations - the *Carré Renard* was found to be the most promising for backscatter. Located in a sheltered part of the bay and close to the entrance of the military harbour, it is 23-m deep and flat, covered with coarse sand and gravel – mixed with some broken shells. The sediment composition is homogeneous over the area, giving a similar homogeneous backscatter response. Previous surveys have shown that the azimuth response is constant – coherent with the fact that no organized roughness of the interface is observable from acoustic or video data of this area. The main biological feature observed is the presence of a dense population of brittle stars. Very little natural variability is to be expected, considering the sediment type and the environment. Moreover this area is not used for fishing, nor oyster farming, and is not either a spot for scallops or clams. The only changes that might be seen could be caused by ships anchoring there, prior to entering into Brest harbour. All the conditions seem to be met for this area to have remarkably stable interface characteristics.

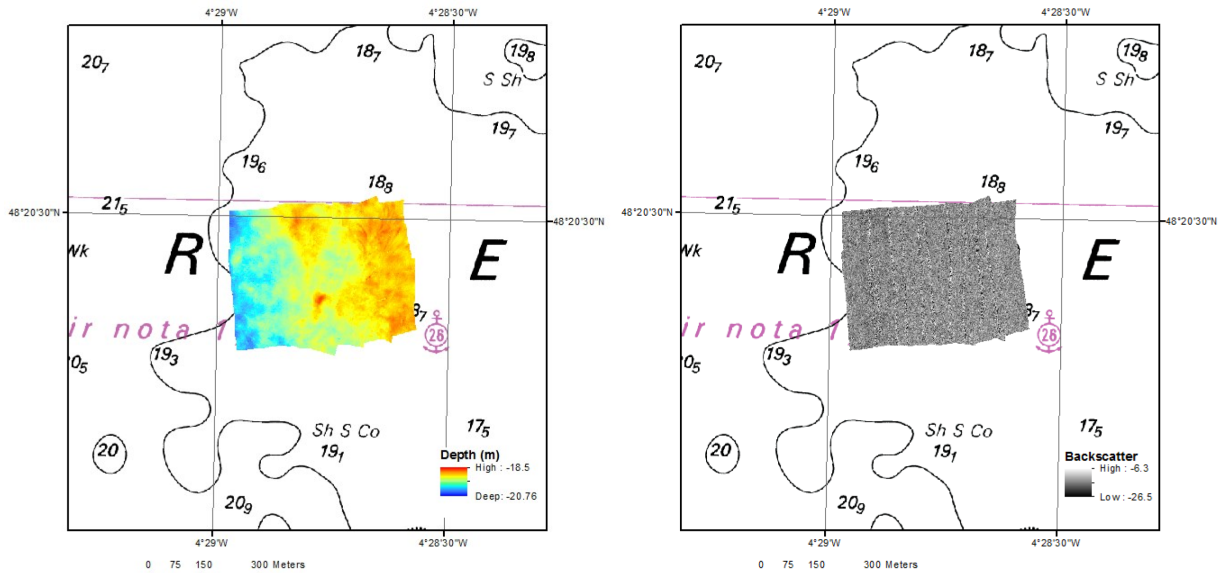

Fig.1. Bathymetry (*left*) and backscatter (*right*) maps of the *Carré Renard* reference area

The *Pierres Noires* is also a candidate reference area for backscatter. Located in the open sea, west of Cape St Matthew, it is a deeper area (about 60 m) than the Bay of Brest, covered with an homogeneous and well-sorted sand (although a gradient of characteristics can actually be observed over the area). This zone (about 1.2 x 2.5 km) is already used by SHOM as a reference area for bathymetry (typically for 100-kHz systems), but has not been regularly surveyed for backscatter until now.

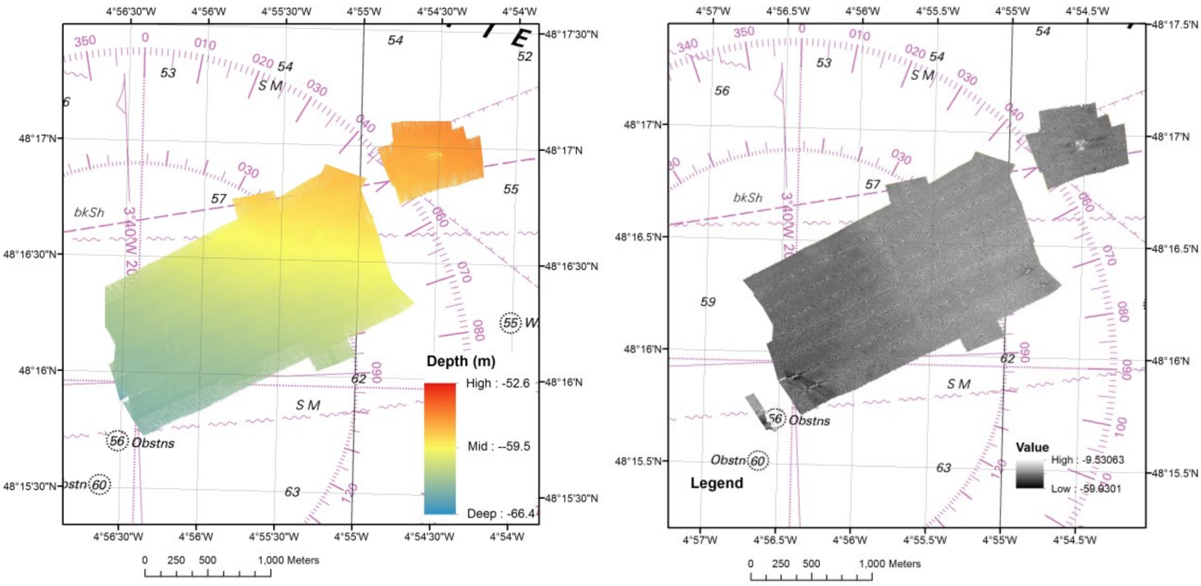

Fig.2. Bathymetry (*left*) and backscatter (*right*) maps of the *Pierres Noires* reference area

4.1.2 Western Solent (UK)

The Western Solent is an area between the English mainland and the Isle of Wight. Away from the main shipping route, it is a navigational cautionary area due to a number of pipelines and cables between the mainland and island. The seafloor consists of rippled gravel beds, made up mainly from gravel and cobbles. Sampling in the area is very difficult due to the consolidated nature of flint the seabed and the high currents of nearly 4 knots caused by the tidal cycles. Over the last 10 years annual surveys have been carried out in this area and it has been seen that the rippled seafloor does not change, suggesting that the area is in sedimentary equilibrium with no erosion or deposition occurring. There are several pipelines that have been trenched and re-buried. These pipelines however are visible as the re-burial material has been eroded away by the strong currents. This therefore suggests that the stability of the seafloor substrate is dependent on an interlocking crust of gravel and cobbles. Dragging of a video camera frame over the area raised very little sediment from the surface and showed very little biological activity, presumably due to the strong currents. Depths vary between 13 and 24m.

The reference area can be easily found being near 50°46.0'N and 1°20.3'W but also south west of an old shipwreck (*SS Algerian*, a freighter sunk in 1916). The area can be also used for calibration of the bathymetry data from the multibeam system, having all the required features.

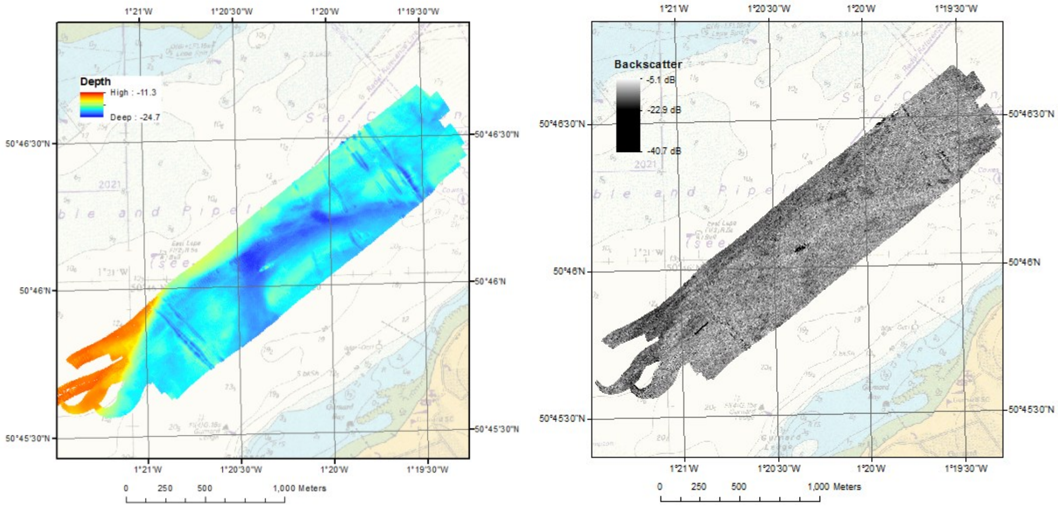

Fig.3. Bathymetry (*left*) and backscatter (*right*) maps of the *Western Solent* reference area

4.1.3 Kwinte KWGS (Belgium)

Easily accessible from the ports of the Belgian coast, the *Kwinte KWGS* area is located in the Flemish sandbank area, inside the Kwinte channel between the Kwintebank and the Buiten Ratel sandbanks (Fig.4). The area is oriented SW-NE and covers 1.75 km² (2.5 x 0.7 km). Since 2009, numerous bathymetry and backscatter surveys using different acoustic systems with *in situ* control (video and samples) have been conducted on this area. A multi-year time series confirm excellent stability of bathymetry and morphology. All bathymetric surveys made since 2009 are compliant with IHO "Special Order" specifications and show no significant observable trend in topography.

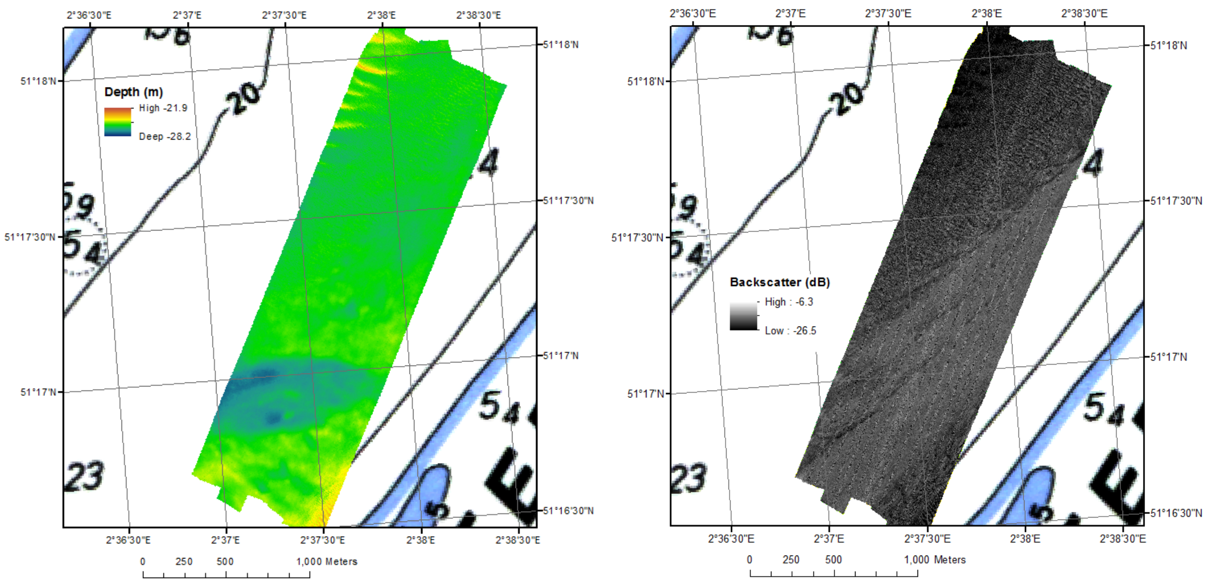

Fig.4. Bathymetry (*left*) and backscatter (*right*) maps of the *Kwinte KWGS* reference area

The area is quite flat with a depth ranging from 21.5 to 25.5 m. From a geomorphological and sedimentological perspective, both bathymetry and backscatter data reveal clearly two distinct sub-areas: the NW part is gravelly sand organized in large dunes, while the SE is homogeneous gravel and sand without any marked dune patterns. Obviously, the measured backscatter level depends on the navigation heading in the NW anisotropic gravelly sand dunes, which is not the case in the SE homogenous sub-area. The boundary between the two sub-areas seems to be stable over time. Trawling traces have been sporadically observed on the backscatter images, but their actual quantitative impact on the BS level averaged over the area is not significant.

The *Kwinte KWGS* characteristics are in accordance with the criteria recommended for reference areas designed to control and calibrate the backscatter levels of shallow MBES systems. Interestingly, the area includes two adjacent sub-areas with clearly distinct features.

4.2 Evaluation cruise

A cruise over the four areas was conducted in June 2015 on *RV Belgica*, aimed at surveying the candidate areas using the same MBES and complementing the sonar survey with ground-truth operations. The objective was multi-fold: to calibrate the *Belgica* MBES over one known reference area (*Carré Renard*), to compare the backscatter characteristics seen in the four areas, and to provide an analysis of variable backscatter data parameters over known common areas.

The sonar surveys used the Kongsberg EM 3002-D multibeam echosounder installed (2007) on *RV Belgica*. This 300-kHz system features two sonar heads on both sides of the ship's hull, active faces tilted 35° from horizontal. The system recorded data inside the [-75°, 75°] incident angle range, each having 512 formed beams of widths 1.5°x1.5°. The MBES was operated with a constant source level, and a nominal pulse duration of 150 µs. However, in order to evaluate the effect of the pulse length on the backscatter, several lines have been logged using the various pulse lengths available (50, 100, 150 and 200 µs).Thanks to favourable weather and sea conditions during the survey period, the quality of all the MBES data was found to be excellent.

The ground-truth operations included a video footage of the interface at selected locations, and sediment sampling. The video camera was installed on a frame deployed over the side of the ship using a small winch; the data were transmitted to the ship, visualized and recorded, making it possible to adapt the strategy of operation (altitude over the seafloor, etc.). The sediment was sampled using a Reineck boxcorer – whose primary purpose was to sample the upper sedimentary interface whilst preserving its stratified structure. Each sediment sample was photographed after collection, and a part of it was taken and preserved for future in-lab grain-size analysis.

4.3 First experimental results

In all cases the data obtained on the various areas confirmed the results from previous surveys using either the same MBES or comparable Kongsberg EM2040 or Reson Seabat 7125 systems. The backscatter level was found to be at a relatively high level, with a weak specular contribution, typical of the hard and coarse sediment facies encountered on these sites.

Regarding the MBES absolute calibration, the initial goal of the experiment could not be satisfied yet, in the sense that a required reference measurement was not available at the time of the cruise. Reference data at 200 kHz had been recorded over the *Carré Renard* area, but availability of a 300-kHz SBES was then in question. Hence a residual systematic bias is still present on the EM 3002 data, and the backscatter levels presented here should not be taken as absolute reference values. However the relationship between backscatter behaviour and angle, and the level difference between areas, are usable. Calibrated reference measurements at 300 kHz are planned for a next cruise in late 2015; and their results will make possible the *a posteriori* accurate adjustment of all the data measured by EM 3002.

A preliminary synthesis of the various data is presented in Fig.5. It features boxplots of the statistical distributions of the BS values recorded over the four areas. Consistent with its small size and the homogeneity of its acoustic response, the almost entire surface of the *Carré Renard* area has been considered for data analysis, while for the three other areas, restricted zones have been defined to avoid effects linked to the “large scale” variability of backscatter over the complete extent (see lower Fig.5). For each area the statistics have been computed (1) over all the incidence angles ±[0°-75°], and (2) over a restricted sector ±[30°-50°]. The average value changes very little between the two angle ranges, while the dispersion is of course much less when only the intermediate angles are considered: the quartile around the median values stay within a ±1 dB range. The *Pierres Noires* area shows the lowest BS median level (around -26 dB) thanks to its low-roughness characteristic of a smooth sandy facies. *Carré Renard* and *Kwinte KWGS* show similar median levels (-14 to -15 dB) typical of coarse sand facies; while the *Western Solent* data are one step above – with median values around -11 dB, characteristic of the very coarse material at the interface confirmed by the video observations.

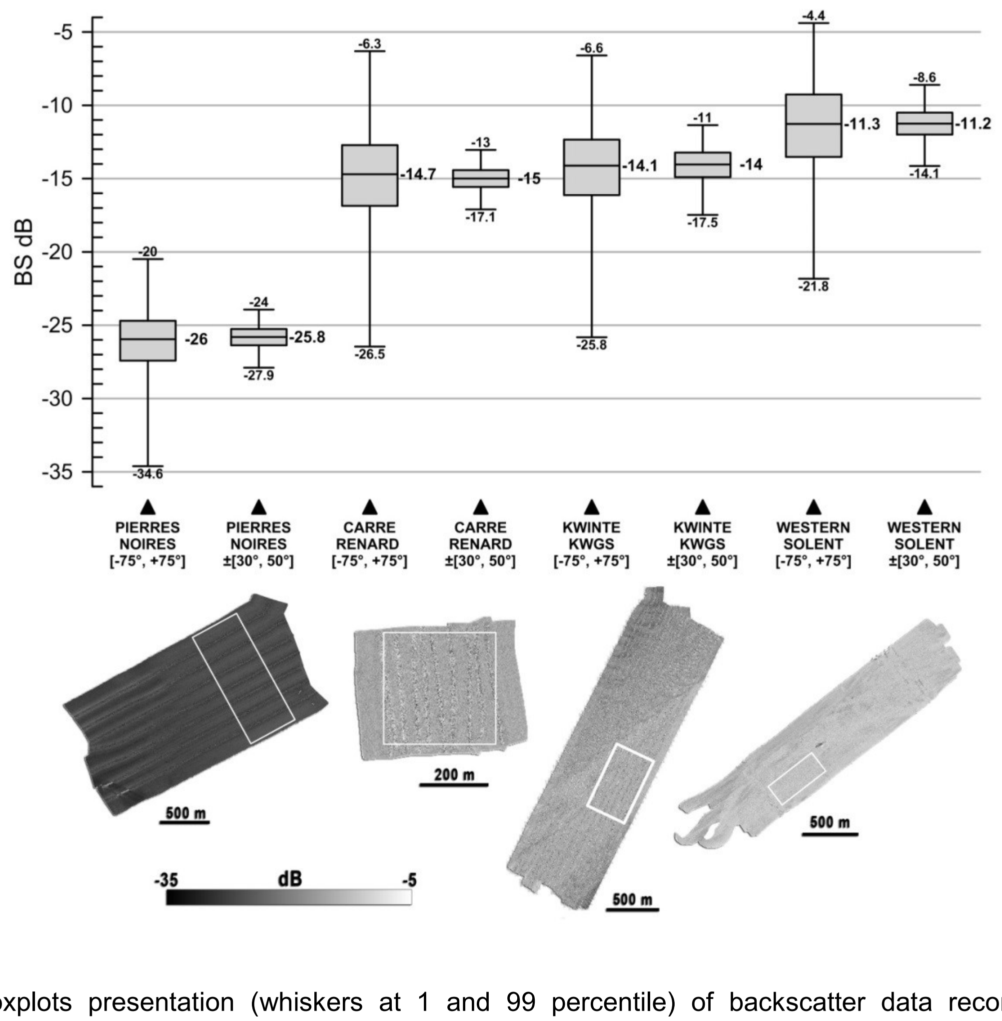

Fig.5. Boxplots presentation (whiskers at 1 and 99 percentile) of backscatter data recorded over homogenous sub-areas of the surveyed areas; backscatter from complete angular extent of the MBES ±[0°-75°] and over a limited sector ±[30°-50°]. Backscatter mosaics gridded at 1x1 m for each surveyed area are shown using the same dB grey level scale. Note the different size of the areas and sub-areas.

5 Conclusions and prospective

The definition of appropriate reference areas for MBES calibration relatively to their intensity measurements is presumably the best option today. This requires selecting appropriate areas, based on the criteria listed and briefly discussed above, and conducting measurement campaigns using a calibrated sonar (namely a tilted fisheries SBES).

A pilot experiment of inter-calibration has been conducted over four reference areas, using the same 300-kHz MBES on *RV Belgica*. The main purpose was to calibrate the MBES over one well-known area (namely *Carré Renard*, although its 300-kHz absolute reference was not available yet), and then to obtain calibrated backscatter levels on other areas (which is done at this stage only in a relative way). The sonar surveys were complemented by ground-truthing operations (observation and sediment sampling), enhancing the knowledge and the understanding of the local geological configurations. All four areas show similar features (flat shallow areas, hard sediment interface, good stability and accessibility) making them good candidates for becoming reference areas for high-frequency MBES calibration.

Given the high coverage density, analysis of the backscatter behaviour *versus* angular sector is in progress separately for the various subareas. The ultimate goal is to describe limited areas with homogeneous characteristics (comparable with the *Carré Renard* configuration) and, by integrating all the available data, provide a backscatter model for the “plateau” angular sector ±[30°-50°] usable as a reference for further measurements. In the longer term, the purpose is to define and promote a “backscatter patch test” equivalent to the standard “bathymetry patch test” routinely conducted[2] with MBES operated for seafloor-mapping.

While the methodology could be defined for shallow-water MBES, and proved to be practical, much is still to be done for deep-water systems for which the constraints are specific and much more difficult to determine. Finding a reference calibrated sensor will not be straight-forward; fisheries SBES frequencies are currently down to 38 or even 18 kHz, but 12 kHz is far less common, whilst this is the usual frequency for deep-water MBES. Also the ground-truth operations on deep areas are less easy: sampling involves deployment lasting several hours per station, and the video footage implies the deployment of very specialized and heavy deep-water ROVs or AUVs.

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