BACKSCATTER STABILITY AND INFLUENCE OF WATER COLUMN CONDITIONS: ESTIMATION BY MULTIBEAM ECHOSOUNDER AND REPEATED OCEANOGRAPHIC MEASUREMENTS, BELGIAN PART OF THE NORTH SEA

M. Roche	FPS Economy, Continental Shelf Service, Brussels, Belgium
M. Baeye	RBINS, OD Natural Environment, Brussels, Belgium
J. De Bisschop	RBINS, OD Natural Environment, Brussels, Belgium and Msc student Ghent University, Department of Geology, RCMG
K. Degrendele	FPS Economy, Continental Shelf Service, Brussels, Belgium
L. De Mol	FPS Economy, Continental Shelf Service, Brussels, Belgium
S. Papili	Belgian Navy, Marine basis Zeebrugge, Zeebrugge, Belgium
O. Lopera	Signal and Image Centre, RMA, Brussels, Belgium
V. Van Lancker	RBINS, OD Natural Environment, Brussels, Belgium

1 INTRODUCTION

Within Europe's Marine Strategy Framework Directive, the benthic habitat is the backbone of many seabed related indicators[1]. To assess its distribution and extent, and the changes over time, seabed mapping is increasingly used (see[2] for an overview). When the habitat structures the seafloor (e.g., dense aggregations of species), the distribution can be mapped directly, though in many cases it is inferred from the seabed type[3,4]. Large areas of the seafloor can be mapped time- and cost-effectively using multibeam echosounders (MBES), and, in combination with appropriate ground-truthing, new insights become available on the status of the benthic habitats[5].

However, for the detection of changes in seabed and habitat types, further evaluation is needed on the precision, sensitivities and repeatability of the acoustic devices. This is especially the case for MBES-derived acoustic backscatter, being a direct proxy of seabed type[6]. Although mapping of backscatter has become standard practice (e.g.[7]), a large scatter exists in the absolute values of backscatter when comparing responses from repetitive surveys. This has now been recognized by the GeoHab Backscatter Working Group[8]. The main aim is to advance and innovate towards well-calibrated seabed backscatter datasets providing ranges of absolute backscatter over the main seabed/habitat types, to be used in a monitoring context.

In this respect, it is of primary importance to additionally quantify all external factors that are not taken into account by the sonar equation itself and that can potentially influence the MBES backscatter. Hitherto, only the absorption coefficient – depending essentially on the temperature and salinity in shallow water - is taken into account by the sonar equation to offset the influence of water mass conditions on the backscatter. Despite numerous examples of suspended sediment quantification using acoustic techniques, few papers are devoted to the influence of turbidity on MBES seabed backscatter. However, as suggested by MBES water column backscatter data[9], by laboratory experiments[10] and also by MBES measurements nearby seabed disturbing activities, suspended sedimentary particles could influence notably the MBES seabed backscatter level. The quantification of that influence remains a major issue in coastal areas as well as in deep waters.

A project involving different Belgian teams has recently started on this topic. An overview of our first results is presented in this contribution and focusses on backscatter stability, water column suspensions and near-bed sediment load[11]. An additional aim was to investigate most efficient ways of quantifying SPM concentrations throughout an MBES survey. Acoustic Doppler Current Profilers (ADCP) provide such means, and can, dependent on the frequency, operate simultaneously, or alternatively, with MBES recordings.

2 STUDY AREA

The Kwinte KWGS study site is located in the sandbank area of the Belgian part of the North Sea, inside the Kwinte gully between the Kwintebank and the Buiten Ratel sandbanks (Fig. 1). The area is oriented SW-NE and covers 1.75 km² (2.5 x 0.7 km²). 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. The area is quite flat with a depth ranging from -22 to -26 m Lowest Astronomical Tide (LAT). 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 part consists of homogeneous gravel and sand without any marked dune pattern. 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, when averaged over the area, is not significant.

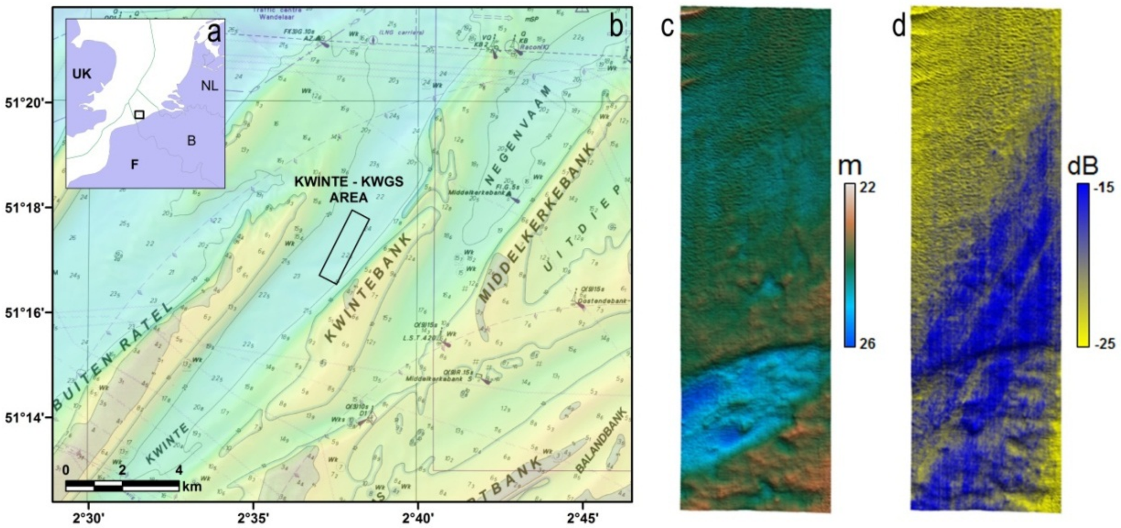

Figure 1 - Geographical location and characteristics of the study site. a: General map showing the Belgian part of the North Sea with coast lines and EEZ limits of neighbouring countries, black square in Belgian EEZ corresponds to map b; b: Flemish Banks' area and location of the Kwinte KWGS study area; c: Bathymetry (m, LAT) – morphology of the Kwinte KWGS area; d: backscatter (dB) of the Kwinte KWGS area; both c and d are averaged reference models derived from several surveys done with the Kongsberg EM3002 dual 300 kHz MBES installed on RV Belgica.

3 MATERIAL AND METHODS

3.1 Survey design

A first experiment to investigate the variation of MBES backscatter, against variation of suspended particulate matter (SPM) in the water column was conducted along a complete tidal cycle (12h) during RV Belgica campaign ST1502, 2-3 February 2015. Figure 2 summarizes the survey design.

RV Belgica's hull-mounted Acoustic Doppler Current Profiler (HM-ADCP) (Teledyne/RD Instruments WH300 kHz) was used, though was only switched on in-between consecutive MBES lines, due to interference with the MBES system. During this time, the ship halted to take vertical profiles of oceanographic parameters with a Seacat profiler mounted with a CTD (Seabird), optical backscatter sensor (OBS) (Seapoint), and an in-situ laser particle sizer (LISST100, Sequoia). Above the Seacat frame, a 10 l Niskin bottle was attached for water sampling to determine the SPM concentration through filtrations (GF/C filters; 3 replicates). The profiles were taken ± every 30' at the beginning and end of a centrally lying reference line in the KWGS area along which MBES measurements were conducted. For the HM-ADCP, a bin size of 0.25 m was set. This size was chosen for a more detailed depiction of SPM variations, but is known to resolve poorly the current strength when using a WH300 kHz system. Since currents and other hydro-meteorological parameters were derived from model results, this was not critical. Taking into account the draught of the transducer and initial acoustic blanking, the first bin was around -6 m. Due to contamination of the lower bins by the strong bottom reflection, data up to 2 m above the bottom were removed.

The MBES used is a 300 kHz Kongsberg EM3002 dual system installed on RV Belgica. The two sonar heads are mounted on blisters that are hull fixed on each side of the keel and tilted at 35° from the horizontal. The system recorded data inside the [-75°, 75°] incident angle range. The EM3002d formed 512 1.5° x 1.5° beams. SIS from Kongsberg was used as acquisition software. A pulse length of 150 µs was fixed during the survey. An absorption coefficient (dB/km) was introduced in the acquisition software at the beginning of the survey according with seawater parameters at that time. In order to minimize the seabed backscatter sources of variations, other than those related to the water column, the measurements with the MBES were performed strictly following the same reference line crossing the center of the Kwinte KWGS area and keeping the same 205° mean heading and using the same runtime and input settings. A total of 15 lines were surveyed every ± 45 minutes.

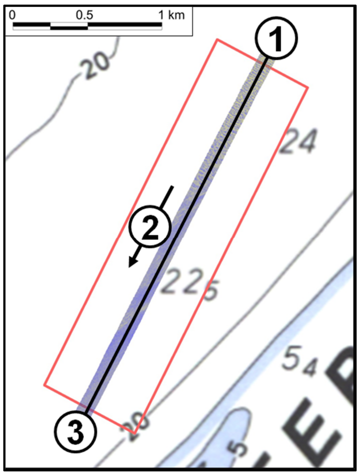

Figure 2 - Survey design.

Red area = Kwinte KWGS area.
Black line = Reference line.

1. Water column measurements and sampling: HM-ADCP Teledyne/RD Instruments WH300 kHz, Seacat profiler with CTD (Seabird), optical backscatter sensor (OBS) (Seapoint), in-situ laser particle sizer (LISST100, Sequoia) and water sampling with 10 l Niskin bottle attached above the Seacat.
2. MBES EM3002d survey of the reference line using constant settings and heading.
3. Same water column measurements and sampling as 1.

1 to 3 sequence = ± 45 min.

3.2 Data processing

3.2.1 Water column data

ADCPs detect the echoes returned from suspended material (i.e. 'sound scatterers') from discrete depths of the water column. Echo intensities, per transmitted pulse, were recorded in counts (also termed the Received Signal Strength Indicator (RSSI)) that provide indirect information on the currents and density of suspended matter ('backscatter') within each ensonified bin. The RSSI counts were converted to acoustic backscatter in decibels (dB) using the echo intensity scale (dB per RSSI count). The echo intensity was multiplied by 0.42 in order to obtain dB values (instead of counts, and accounting for sound absorption, beam spreading and battery decline)[12]. For this paper, the dB values were converted to mass concentrations of suspended particulate matter (SPM in gl^{-1}), by calibration against SPM values derived from water filtrations during several field campaigns. Later on, in-situ derived SPM concentration values will be used for this calibration. To enable analyses against the results from the Seacat vertical profiles, and MBES backscatter variation, vertical profiles of SPM were extracted from the HM-ADCP data at the time of sampling. These were then further analysed statistically.

Voltages from the Seapoint OBS were converted also to SPM ($g\ l^{-1}$) following the instruments' specifications and calibration against the results of the water filtrations. For the lower turbidity values a factor of 7.043 was found between the Seapoint NTU values and the filtration results (coefficient of determination: 0.958 in the range of 0-0.030 $g\ l^{-1}$).

3.2.2 MBES seabed backscatter

The MBES backscatter data processing was performed with Sonarscope from Ifremer. Figure 3 summarizes the backscatter processing steps as applied to each of the surveyed lines. BS processing was conducted line by line. For each mosaic, a incidence angle compensation was applied using an average compensation curve based on all data. A restricted area was defined to calculate the backscatter statistics over a homogeneous seabed, avoiding the influence of backscatter variability due to larger scale sediment heterogeneity. For each compensated mosaic, subareas, including values inside the ± [35° - 45°] angular sectors, have been extracted from the restricted common area. The intersection of these areas set a final common sector of the seabed over which the backscatter statistics, established line by line for a same angular sector, were compared.

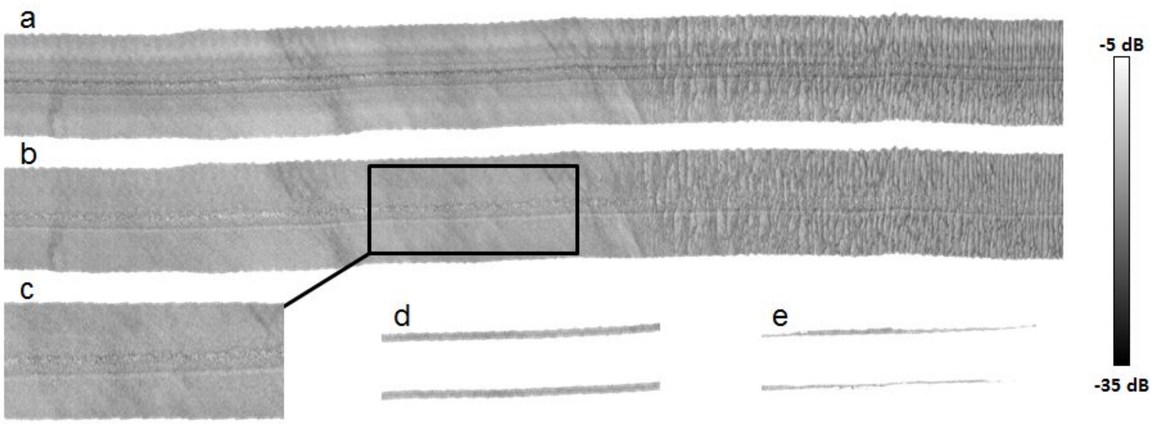

Figure 3 - MBES seabed backscatter processing steps. a: raw data; b: compensated data accounting for the incidence angle; c: selected data in a restricted homogenous area; d: extraction of values inside the ± [35°-45°] angular sectors; e: common insonified area of the 15 lines on which backscatter statistics were established.

4 RESULTS AND DISCUSSION

To investigate the variation of MBES backscatter against the variation of SPM, three categories of results can be considered on the basis of this first experiment: the short time MBES seabed BS overall stability and quantification of small-scale fluctuations; the SPM fluctuations; and the relationship between the two categories of variables. Figure 4 presents all the variables over a common time-scale.

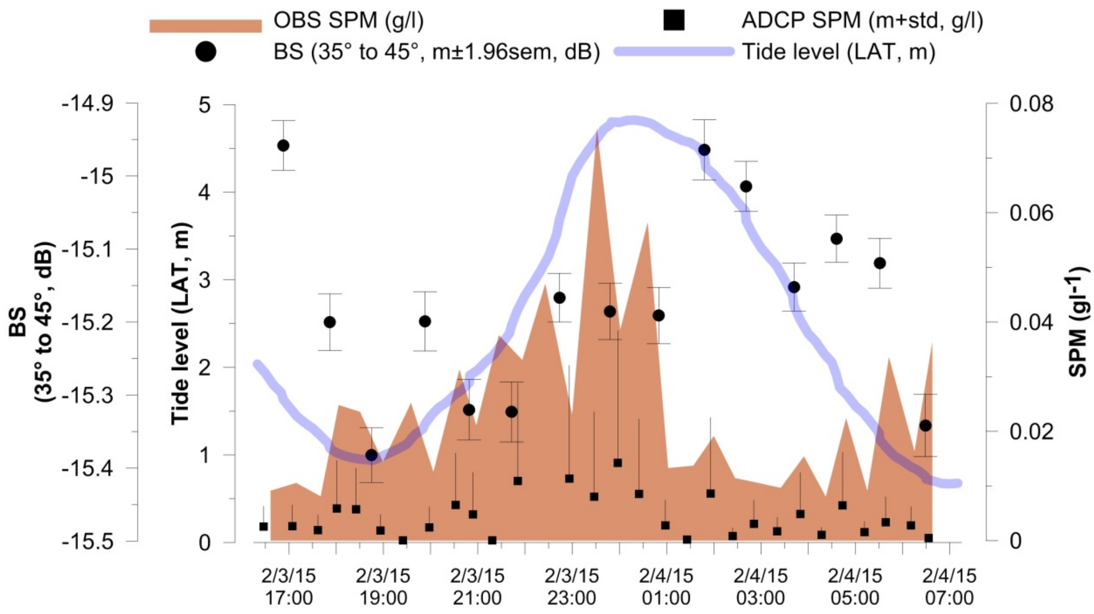

Figure 4 - Summary graph showing all the results from the repetitive measurements conducted in the Kwinte gully of the Flemish Banks (16 km offshore) during one tidal cycle (3-4/2/2015; UTC time): SPM concentrations (gl^{-1}) derived from the OBS sensor (light brown filled area) and from the HM-ADCP (black square); HM-ADCP: average value over the water column (m) + the standard deviation (std); OBS values were obtained closest to the bottom (± 4 meters above the bottom); Mean MBES EM3002d backscatter levels. These were obtained from the same heading and location lines and were restricted to ± [35° - 45°] incidence angular intervals in a commonly insonified seabed area (black dots) (95% confidence interval; 1.96 standard error of the mean (sem)). Tide level (m, LAT) (blue line).

The short time backscatter stability was estimated through the variance associated with the average backscatter level of successive measurements. The variance between the average levels of BS measured during the 12-h tidal cycle on a homogenous seabed area and for a restricted ± [35° - 45°] angular sector was extremely low (range = 0.4 dB and std = 0.13 dB). From this, the average level of MBES seabed backscatter can be considered stable. Considering that 1 dB is a required accuracy necessary to discriminate the main classes of sediments on the basis of their mean backscatter response[8], our results demonstrated that the EM3002d satisfied this metrological requirement, at least over a short period. Considering the backscatter mean level in function of time, despite their relative limited amplitude according to the confidence intervals, the fluctuations of BS mean level were globally significant. Referring to Fig. 4, these fluctuations may be attributed to the tidal level, hence variation in water column properties.

The results on SPM variation varied significantly between the acoustic and optical devices and is work in progress. For this paper, the ADCP-derived SPM concentrations were obtained using water samples from previous campaigns and not yet the in-situ samples. For the OBS-derived SPM concentrations, a proper calibration was done. Another bias was the difference in measuring height between the two sensors, rendering comparisons difficult. This will be procured in the near future, incorporating uncertainty estimations for both devices. However, on a relative scale, both sensors derived increased SPM concentrations around High Water (HW) (from -3 h to around HW), and dropping abruptly afterwards. These trends will be further compared with measurements in adjacent areas (both near- and offshore), as well as with model results (OPTOS-BCZ, RBINS OD Nature).

However, for a first assessment of the correlation between the MBES seabed backscatter and SPM concentrations, mean values were used from the MBES, and for SPM an average was calculated from the measurements just before and after the MBES lines. Using the raw values, no significant linear correlation (Pearson r) was observed between the backscatter values and both ADCP and

OBS SPM values. However, by considering the rank values, a slight, but significant, linear negative correlation (Spearman rank correlation = -0.59) was observed between backscatter and SPM derived from OBS measurements (Figure 5).

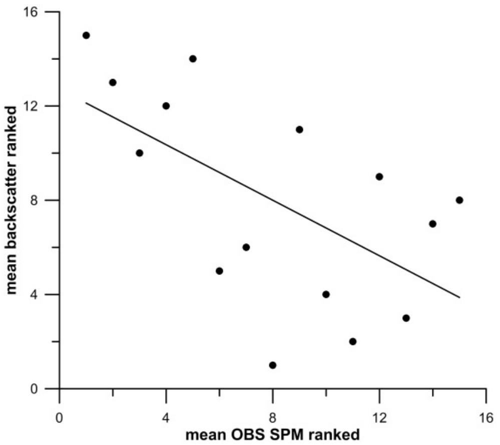

Figure 5 – MBES seabed backscatter with SPM values derived from OBS rank correlation.

Spearman rank correlation = -0.59
p-value = 0.023

Coefficient of determination = 34.7 %

This trend suggests that SPM concentration in the water column could have some influence on the seabed backscatter. The correlation is significant, though it explains only a minor part of the backscatter variance (coefficient of determination = 0.347). No significant correlation was observed between the backscatter and the SPM derived from ADCP measurements. This might be due to the longer distance of the measurements above the bottom, compared to the SPM derived from the optical sensor.

5 CONCLUSION AND PROSPECTIVE

A first experiment to investigate the variation of MBES backscatter, against variation of suspended particulate matter (SPM) in the water column was conducted along a complete tidal cycle (12 h) during RV Belgica campaign ST1502, 2-3 February 2015 on an area in the Kwinte gully in a sandbank area of the Belgian part of the North Sea.

Several techniques were used to investigate water column SPM and oceanographic parameters: Acoustic Doppler Current Profiler (ADCP), a Seacat profiler with a CTD, an optical backscatter sensor (OBS), a water sampler and a laser particle sizer. MBES seabed backscatter was obtained with a 300 kHz Kongsberg EM3002 dual system. In order to minimize the seabed backscatter sources of variations other than those related to the water column, the measurement with the MBES were performed strictly following the same reference line keeping the same heading and using the same runtime and input settings. Water column and MBES measurements have been done sequentially with a duration of ± 45 minutes for each measurement cycle.

The variance between the average levels of BS,, measured during the 12-h tidal cycle was extremely low (std = 0.13 dB). Over this short time interval, the average level of MBES seabed backscatter can be considered as fully stable relatively to the 1 dB required accuracy necessary to discriminate the main classes of sediments. Despite their relative limited amplitude, according with the confidence intervals, the measured fluctuations of BS mean level were overall significant. The similarity between the backscatter mean level fluctuations and the tidal level suggested that the slight backscatter fluctuations could be influenced by water column parameters.

Using the raw values, no significant linear correlation was observed between the backscatter values and both ADCP- and OBS-derived SPM values. However, by considering the rank values, a slight, but significant linear negative correlation was observed between backscatter and SPM derived from OBS measurements. The minimum distance above the bottom at which the concentration of SPM is estimated is a key issue. Ideally, near-bed (as near as possible to the MBES detection window) measurements should be conducted (quasi-)simultaneous with the MBES recordings. In-situ instrumentation (e.g., benthic landers) may be considered, though this may not be practical from a MBES monitoring perspective that is inherently wide-spread in space.

Finally, we need to emphasize that this first experiment was conducted in a gully (-22 to -26 m LAT), where coarser sediments prevailed and where SPM concentrations are generally low. Much more fluctuation in MBES seabed backscatter and SPM concentration is expected on shallow sandbanks and in muddy coastal zones. Similar experiments are expected to be conducted in these environments.

6 References

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