

Appendix

1. Guideline for multibeam backscatter data acquisition

The section provides a guideline to acquire suitable multibeam echosounder (MBES) backscatter data for sediment and habitat classification in the North Sea. This guideline represents a general description of the required and recommended MBES settings independent of the MBES model and manufacturer. A more detailed description might be necessary if the MBES model is known. Recommended and required settings will be distinguished. The required settings are absolutely necessary to consider by the surveyor for the acquisition of useful MBES backscatter data and eventually the production of sediment and habitat maps. In case of the recommended settings, the surveyor should know that these settings are recommended but if the quality of the bathymetry data deteriorate significantly, the settings can be adjusted. In general, all settings are recommended to be constant during the survey in order to achieve comparable backscatter results.

Equipment on board

- Multibeam echosounder
 - Sonar interface module (SIM)
 - Necessary cables
 - Sound velocity probe at sonar head
 - In case pole mounted, pole is required
- Motion Sensor
- Positioning Sensor (ideally RTK)
- Sound velocity probe (for water column profile)
- Acquisition computer
- Acquisition software
 - SIS (Kongsberg internal software)
 - QINSY (OPS external software)

Required MBES settings

- Constant frequency
- Constant pulse length
- Pulse type: Continuous wave (CW pulse)
- Constant swath coverage
 - between +/-60° and +/-70°

Recommend MBES settings

- Frequency between 200 and 400 kHz, most common 300 kHz (valid for shallow water depth between 10 to 50 m)
- Pulse length between 100 and 300 μm , most common 150 μm (valid for shallow water depth between 10 to 50 m)

- Single-swath mode
- Beam spacing: equiangular

Additional considerations

- Regular measurements of the water column properties (conductivity, temperature and depth (CTD)) are required for the calculation of the sound absorption. The sample device needs to be a CTD device, which can also be used for the calculation of the sound velocity profile. The sampling interval depends on the water dynamics and the spatial and temporal variation in the water column properties. As an example, the highly dynamic Wadden Sea required a higher sampling interval than the more stable open North Sea. A good estimator for the change in water column properties is given by the sound velocity probe mounted at the MBES providing real-time measurements of the sound speed. A rule of thumb is that when the sound speed changes by 2 m/s compared to the last CTD measurement, a new CTD measurement is required.
- Crosslines for data control are recommended. Crosslines are survey lines perpendicular to the regular survey lines.

Advising companies/people

General Advise:

- TU Delft: Leo Koop, L.Koop@tudelft.nl
- Freelancer : Timo Gaida, timogaida@gmx.de

MBES and software specific advise:

- Kongsberg MBES and SIS acquisition software – Kongsberg support: e.g., Kevin Weerman (Kevin.Weerman@km.kongsberg.com)
- R2 Sonic MBES - R2Sonic support: e.g., Samantha Bruce (Samantha.Bruce@r2sonic.com), Mike Brissette (Mike@r2sonic.com)
- QINSY acquisition software - QPS support (www.ops.nl)

2. Guideline for side-scan sonar acquisition

General information

The side-scan sonar (SSS) has the advantage over the MBES in obstacle detection, like boulders, reefs or pipelines. Due to a generally higher resolution, it might also be more suitable for reef detection. For objective and automatic sediment and habitat mapping the MBES is preferred.

Equipment on board

- Side-Scan Sonar
 - Winch
 - Cables
- Positioning Sensor on the vessel
- Underwater positioning systems on the SSS called USBL is recommended but not strictly necessary

- Acquisition computer
- Acquisition software
 - Often acquisition software comes with SSS

Required SSS settings

- Constant frequency
 - Constant pulse length

Recommend SSS settings

- The higher the frequency the better resolution, but the smaller the covered area. Still, high frequency is recommend for biogenic reefs (>400 kHz)
- Well documented sonar settings for post processing

Additional considerations

- HKZ project has shown that SSS track lines parallel to crest of sand waves are more suitable than orthogonal to crest. If current and weather state allows SSS track lines parallel to crest, these line should be majority of the lines. Still crosslines should be sailed as well.

3. Guideline for ground truthing

The first very important remark is the timing of the ground truthing. The ground truthing should be carried out as close as possible to the acoustic data acquisition. Ideally, the acoustic data will already be preliminary analysed on the vessel and based on the observed acoustic pattern a location for the ground truthing will be chosen. The ground truthing could be done from the vessel as the acoustic acquisition.

In general, a combination of physical samples (e.g., box corer, Van Veen sampler) and video footage is recommended. However, if budget constraints only allow one of them, video footage would be recommended for identifying biogenic reefs and box coring for the production of a sediment map.

Van Veen sampler vs. box corer

For physical samples, a box corer is always recommended even though box coring is more demanding than Van Veen sampling. A box corer allows to retrieve a sample of the undisturbed seabed and even provide information from the first 50 cm of the seabed (like a coring device), thereby revealing shallow sediment layering. This can be very helpful, for example if a thin mud veneer on top of sandy layers exists and is therefore crucial for interpreting the acoustic data.

Importance of appropriate documentation

In general, all observations about the sample on the vessel should be well documented.

For coarse grains, such as gravel or shell fragments, a larger sample size (e.g., 200 g) than for fine sediments (e.g., 10 g) is required in order to receive a reliable grain size analysis in the lab. In addition, a good documentation already done on the vessel, including a foto, is of high importance to the acoustic analysis.

4. Processing steps

The processing of the MBES data is carried out with commercial software and TU Delft in-house developed software. The commercial software allows a relatively quick processing with a well-designed user interface. The MBES backscatter processing is carried out with the QPS software called FMGT (www.qps.nl) allowing a quick processing on the vessel in order to define suitable ground truthing locations on the fly. The MBES bathymetry processing is carried out with the QPS software Qimera (www.qps.nl) allowing a detailed 3D visualization of the bathymetry. In particular, the manual filtering of artifacts is very effective. While in general the commercial software is more user friendly, the TU Delft software has the advantage that it can account for unpredicted errors in the data by adding additional processing steps. Of course this requires some knowledge about the MBES and programming skills in Python or Matlab. The main reason for the necessity of the TU Delft software is that it is compatible with the acoustic classification code (see Section 5). It provides the input data for the acoustic and sediment map production. In addition, the raw data and corresponding sonar parameters can be investigated. This is of importance in case unexpected errors are found. Theoretically, the output of the commercial software can be used in the acoustic classification method as well. However, the code would require adjustments and not all sonar parameters can be investigated hampering a detailed dataset specific analysis.

Overview of steps in TU Delft processing software

1. Importing raw data
2. Synchronization of data streams
3. Georeferencing of soundings
4. Coordinate transformation
5. Rough filtering (bad coordinates, backscatter, depth and beam angle outliers)
6. Across-track stripe filter (due to for e.g. water bubbles)
7. Automatic spline bathymetry filter
8. Seabed morphology correction
9. Preparation for classification method: data grouping per beam angle and ping
10. Backscatter mosaicking, i.e. removing angular dependency of backscatter data

Advising companies/people

TU Delft software

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Commercial processing software:

- Qimera (bathymetry processing software): QPS support (www.qps.nl)
- FMGT (backscatter processing software): QPS support (www.qps.nl)

5. Map production and interpretation

Backscatter mosaics

Backscatter mosaics can be visualized via the commercial software FMGT and exported as an ArcView Grid or Tiff file into GIS software for further visualization and interpretation. When using the TU Delft software the processed backscatter data can be imported into GIS software or the open source software SAGA for gridding. SAGA is an open source variation of GIS. Based on the variation in the gridded backscatter values in combination with a-priori geological information or ground truthing, the backscatter mosaics can be interpreted.

Acoustic classification

The acoustic classification aims to classify the input data into distinct classes, which ideally represent specific properties of the seabed, such as sediment type or habitat. As input data, data can be used which obtains information about the seabed property to be classified. Since the MBES backscatter is very sensitive to changes in seabed properties, commonly only the backscatter data is used as input data for the classification method. However, different input datasets, such as bathymetry or second order derivatives can be incorporated as well. A well-documented and well-proven classification method for backscatter data is the Bayesian seabed classification method (Simons & Snellen 2009; Amiri-Simkooei et al. 2009; Gaida 2020). The software is written in the coding language Matlab and requires knowledge about Matlab and an understanding of the Bayesian method. For a detailed technical explanation of the method, following literature is recommended: Simons & Snellen 2009; Amiri-Simkooei et al. 2009; Gaida 2020).

Overview of steps in the Bayesian seabed classification method

1. Estimation of number of acoustic classes that can be discriminated based on the backscatter data
2. Selection of reference beam angles and estimation of class boundaries
3. Calculation of class boundaries for three reference angles
4. Assignment of acoustic class to full angular range
5. Gridding

Advising companies/people

TU Delft software

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Commercial processing software:

- GIS: ESRI support (www.esri.nl)
- SAGA: support via online forum

6. Theoretical background

While radar (radio detection and ranging) or optical sensors are used to map the terrestrial surface, mapping the bottom of the oceans in a similar spatial resolution requires to a large extent the use of acoustic sensors (Mayer et al., 2018). Acoustic depth measurement systems, such as those obtained from the multibeam echosounder (MBES) and singlebeam echosounder (SBES), measure the elapsed time that an acoustic pulse takes to travel from a generating transducer to the seabed and back. This is illustrated in Figure 1 where the measured depth is between the transducer and some point on the acoustically reflective bottom. The travel time of the acoustic pulse depends on the sound speed in the water column. If the sound speeds in the water column are known, along with the distance between the transducer and the reference water surface, the depth can be computed by the measured travel time of the pulse. The big advantage of the MBES over the SBES is that during the reception, beam steering allows to estimate the travel time of the signal for a large number of predefined beam angles along the swath (Figure 1), thereby allowing to scan an area on the seafloor of up to seven times the water depth.

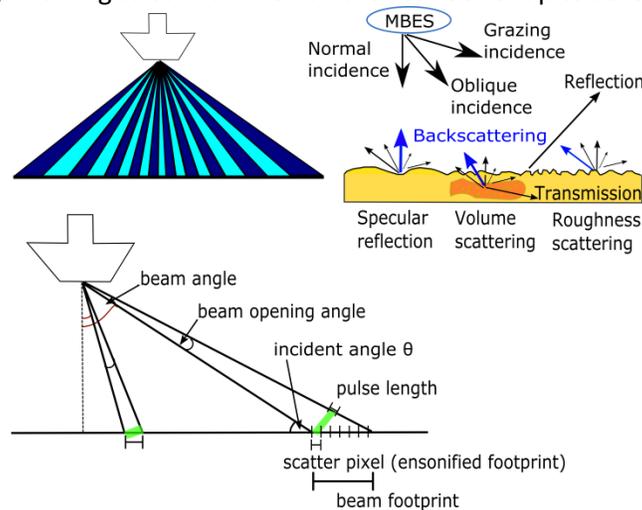


Figure 1 MBES and backscattering theory.

Multibeam systems can also collect information about the type of seafloor. Different seafloor types “scatter” sound energy differently and hence return the signal with different levels of energy. This is known as backscatter (Jackson & Richardson, 2007). Therefore, backscatter information can be used to determine the physical nature of the bed and distinguish among seabed sediment types. For example, a softer bottom such as mud will return a weaker signal than a harder bottom, like rocks or gravel.

Since the MBES emerged in the late 1970s, it has become the most valuable tool for seafloor mapping providing high-resolution bathymetry and acoustic backscatter datasets (Lecours et al., 2016). Various classification methods, employing MBES bathymetry, backscatter, and their second order moments, have been developed to characterize sea- or riverbeds in the last two decades (Brown et al., 2011).

Multibeam echosounder vs. Side-Scan sonar

Acoustic imaging of the seabed involves two different mechanisms. The first one requires that the acoustic sensor is closely above the seabed where the obstacle hinders the propagation of the acoustic wave (i.e., acoustic shadowing) (Blondel, 2009). The second process is directly related to the sound scattering at the seabed, where the frequency, the incident angle and the composition of the seabed

determines the amount of the scattered energy (Jackson, 2007). This process is physically quantified by the backscatter (BS) strength, which is defined as the ratio between the intensities of the backscattered and incident wave per unit area (expressed in decibels) (Lurton, 2010). Whereas the acoustic shadowing is mostly beneficial for the Side-scan Sonar (SSS), the actual measurement of the BS strength is of use for both the SSS and MBES. Even though the SSS mostly achieves higher spatial resolution because it is towed closer to the seabed and thus shorter sound pulses and higher frequencies can be applied, the MBES outperforms the SSS in terms of BS processing capabilities. Beam steering during sound reception at the MBES not only enables the determination of the water depth across the sonar swath with an accurate geographical positioning but also provides the angles of the incoming signals in the various beams. The measured seabed morphology in combination with the angular information allows to measure the backscattered signal as a function of the incident angle on the seabed. This provides the following advantages: firstly, it allows to produce a precise georeferenced acoustic image, called BS mosaic, in which the angular dependency of BS is removed; secondly the BS angular response curve, which is characteristic for each sediment, can be employed as an additional sediment characterization tool. Measuring remotely the relative BS strength enables to characterize and distinguish sediments over larger areas with a remarkable quality (Gaida, 2020).

Backscatter processing

To derive the actual BS strength from the received echo at the sonar, the influence of the environment (e.g., water column properties, seabed morphology) on the sound propagation as well as system effects (e.g., sonar settings, transducer sensitivity) during the transmitting and receiving process requires consideration (Lurton, 2015). The transmitted signal with a predefined source level is attenuated due to sound absorption, scattering and energy spread along the travel path in the water column. These losses of energy are called transmission loss. Sound propagation effects can be corrected for by measuring the water column properties and using sound propagation models. When the signal reaches the seafloor, it ensonifies an area of the seabed. In this area, the signal is reflected, refracted and scattered and only a small part of energy is scattered back towards the transducer in the arrival direction (backscattering, Figure 1). Since the backscattering also depends on the incident angle, the slope of the seabed has to be taken into account. The proportion normalized per unit area between the backscattered energy and the incident energy is called the backscatter strength of the seabed (Figure 1). Imperfect calibration of the MBES often complicates the measurement of the actual backscatter strength, and therefore the measured and processed data are often considered as a relative measure of the backscatter strength. Once the relative backscatter strength is retrieved and the angular dependency is removed, a precise georeferenced acoustic image, called the backscatter mosaic can be obtained.

Acoustic sediment and habitat classification

Traditional sediment or habitat mapping was purely based on in situ measurements (e.g., bed samples or sediment cores), which were extended to large-scale maps by interpolation techniques or expert interpretation. In fact, in situ measurements provide locally a detailed and accurate description of the seabed properties but it is difficult to obtain an accurate representation of the large-scale seabed heterogeneity.

The development of acoustic techniques allowed to couple the conventional in situ sampling with the extensive acoustic data to extend the detailed information to a large area and to reveal small-scale heterogeneities. With increasing computing performance, acoustic sediment classification methods

were invented to automatically and objectively classify the acoustic data in order to produce large-scale thematic maps (e.g., sediment or habitat maps) (Brown et al., 2011). In general, the approaches are divided into two different categories, that means, model (physical) and image-based (empirical) methods. The former compares different characteristics of the acoustic data, such as the signal echo envelope or the angular response pattern of the backscatter strength, with physical models to reveal the seabed properties via an inversion process (e.g. Snellen et al., 2011). Image-based techniques explore acoustic patterns and statistical relationships of similar BS features (e.g., relative BS strength, angular response pattern or textural features) (e.g. Amiri-Simkooei et al., 2009). While model-based techniques require no ground truth information in theory, this approach highly depends on a calibrated system and works poorly in complex environments where it is difficult to model the interaction of the acoustic pulse with the seabed. Contrary, image-based techniques need ground truth information, but can be applied to uncalibrated data and are applicable in complicated environments as long as they are sufficiently sampled. In addition, image-based techniques can also incorporate other environmental predictors, for instance, bathymetry and their second derivatives or even hydrodynamic information (e.g. Eleftherakis et al., 2014).

7. Literature

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