Multi-band, calibrated backscatter from high frequency multibeam systems as an efficient tool for seabed monitoring

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Abstract— *Multibeam echosounders are routinely used to provide information on the bathymetry and geomorphology of the seabed. At the same time, more and more users are exploring the full potential of sonar systems as a tool for marine environment monitoring. Benthic habitat mapping using remote sensing methods gives broad-scale information about the geographical range and distribution of marine habitats on the seafloor together with substrate characterization. The crucial element of data collection and processing for that purpose is backscatter, the echo intensity recorded concurrently with bottom detections. The acoustic response of the seabed depends not only on sediment type or its roughness but also on signal frequency and angle of incidence. By introducing more frequencies to our data collection we can capture more environmental information and make a prediction of the geographical distribution of benthic marine habitats and seabed types more accurate.*

Keywords—multibeam echosounder; habitat mapping; bottom classification; calibrated backscatter

I. INTRODUCTION

Multibeam data collection is in general an expensive process but using recent, compact, and integrated solutions we can make a survey faster and less expensive with great benefit in maximizing the information derived from them.

This study aims to present a wideband multibeam solution with a multi-band backscatter that together with a fully stabilized swath for roll, pitch and yaw gives survey hydrographic quality bathymetry together with high standard backscatter. This setup allows for full control of angular parameters influencing the backscatter.

Using multi frequency backscatter data is still a challenging task and a relatively new concept [1]. The physical relationships between multiple frequencies and different sediment types are complex, and the various contributions cannot be easily separated [2]. Echo intensity comprises of surface and volume scattering. However, for high frequencies (>200kHz) the latter has a very small impact. There are also environmental and physical parameters influencing echo signal. One can measure sea water characteristic (salinity, temperature) and compensate for transmission loss. What is often missing is multibeam sonar calibration that allows for accurately quantifying seafloor properties. Having backscattering strength for sonar beams one can relate backscatter values to physical models of seabed acoustic response and compare different surveys even at different frequencies or setups [3]. It was shown that especially fine sediments has variable frequency response but there is a constant development for better interpretation of backscatter information.

The data samples presented here were collected using NORBIT WINGHEAD multibeam i77h from a small motorboat in a coastal area of the South Baltic Sea together with ground-truth samples. The system was calibrated to derive

Backscatter Strength Output (BSO) which is the absolute intensity response of the bottom. The data was collected at different frequencies between 200kHz and 580kHz in shallow water up to 25m depth. Data were processed and mosaics produced with full compensation of the signal for environmental parameters, footprint area and electronics variables. Bathymetry together with backscatter layers is input for the image classification algorithms and angular response curves. Bottom characterization is presented as a sediment class map and related to seabed samples with grain distribution calculated.

The objective of the study is to show how BSO together with a multiple frequency approach can increase the capability of multibeam systems for habitat mapping and marine environment monitoring, limiting steps in the data processing chain and decreasing ambiguity of acoustic results.

II. MATHERIALS AND METHODS

A. *Survey area*

Data were collected in the South Baltic Sea by the Polish central shore, next to Gdynia harbor (Fig.1.) in the area of Puck Bay.

The evolution of Puck Bay was significantly influenced by the processes of deglaciation and later post-glacial transgression. The Puck Bay is separate from the open sea by the sandy barrier - Hel Peninsula. Mean depth of the area is 15.5m [4]. Based on geological maps and previous surveys 5 areas were chosen as test sides. The area 2 that we describe in this study is placed among sandy ridges, bedforms oblique to the shore, and locally covered by thin layer muddy-sand and sandy-mud [5]. Between ridges there is fine sand, sandy mud and also organic matter, on the crests usually there is fine to coarse sand. Closer to the shore one can observe also till outcrops residuals but this was not observed in the test side 2.

Fig. 1. Map of Europe (in the lower right corner) with white square showing the Puck Bay and zoom on the test area 2 on the left.

Organic matter is also present in the research area, not only as a part of subsurface small benthic communities but also big structures of mussels colonies that grow in different shapes in the Puck Bay region and change significantly bottom acoustic properties.

The test area 2 is 2.5km from the coast (Fig.1.) with depth range of 13m-14.6m. Weather during data collection was windy, up to 4 in Beaufort scale. The whole campaign took place in 2022 between 26.08 and 7.09.

B. *Acoustic data collection*

Hydroacoustic data were acquired using a 6m long motorboat equipped with a pole mounted multibeam echosounder (MBES) NORBIT WINGHEAD i77h. Positioning of MBES was based on two antennas placed on the pole on a 2m long bar (Fig.2). An integrated GNSS/INS navigation system Applanix Ocean Master is combining motion data and 2 antennas heading and positioning information in RTK accuracy. The system is light weight and compact.

NORBIT WINGHEAD i77h collects 1024 beams in each swath at frequencies between 200kHz up to 700kHz with angular resolution of 0.5°x0.9° (at 400kHz). Data were collected at 200kHz and 400kHz with swath opening up to 140° (maximum is 210°) in equidistant mode. Our measurements were performed with a maximum ping rate of 30 Hz and a sweep time of FM pulse 500 µs. Norbit MBES has its own sound velocity probe that gives constant information about sound velocity in water close to head supporting beamforming process but for bathymetric survey a sound velocity profiler is also needed. We used Velodyne AML-3 SVP with pressure and temperature sensors which allows salinity calculation along the water column.

The main focus was to collect backscatter data related to acoustic properties of seabed, so together with bottom detections also snippets were collected. Snippets are fragments of echo signal for each beam related to acoustic footprint on the bottom [6]. The MBES has also a special calibration file that corrects the echo for hardware characteristics and after environmental corrections the system is outputting BSO giving absolute values for bottom reflectivity.

Fig. 2. The motorboat with the T shape pole mounted on the port side. In the left corner WINGHEAD i77h multibeam drawing.

Corrected snippets (BSO) are stored in s7k files inside telegram 7058 together with full navigation solution.

C. *Acoustic data processing*

Acoustic data stored in NORBIT native format were replayed in NORBIT GUI (graphical user interface) to correct them for environmental parameters and export as s7k files. Acoustic signal, while traveling trough water column is losing the power due to transmission and absorption processes. Knowing temperature and salinity of the water one can estimate this parameters and calculate proper compensation for the echo strength [6]. We used following corrections for 200kHz: spreading=40 and absorption=25dB/km; 400kHz: spreading=40 and absorption=57dB/km. This calculation was based on average water depth (13m), salinity of Baltic Sea is very low (~8 PSU), the water temperature in the summer was in average 21°C and mean sound speed around 1490m/s. NORBIT GUI is processing the backscatter data and compensating them also for footprint assuming flat bottom [3].

The s7k data were imported to QPS QIMERA post-processing software where they were corrected for sound speed using collected profiles. Bathymetry grid of 25cm resolution was created and cleaned from spikes. After the first stage of processing, data were exported as GSF format including backscatter information and imported to QPS FMGT software. This application corrects echo signals using angle varying gain (AVG) procedure and despeckling signal creating after all high resolution and good quality mosaics.

Both data types: bathymetry and backscatter were used later for statistical parameters calculation and classification in ArcGIS and Matlab softwares. Last step was to combine ground-truth samples with classification results and compare with physical models.

D. *Ground-truth samples collection and analysis*

Bottom samples were collected using a small Van Veen grab sampler from the same motorboat (Fig. 3.). Later in the laboratory sediments were analyzed (dried and seed) using Gradistat algorithm [7] which allows for grain size estimation and sediment type characterization.

Fig. 3. Small Van Veen grab sampler.

Together with grab samples we collected video recordings from each place to have also visual documentation of the seabed. GoPro 8 camera was used with water proof housing and underwater light. We positioned all the ground-truth samples using multibeam navigation system and QPS QINSy software.

III. RESULTS

A. *Bathymetry and backscatter maps*

All the data are presented in UTM 34N projection that is suitable for central Poland. Bathymetry from the test area is rather flat. This is a zone of buried and eroded sand ridges, separated around 250m from each other and only 0.5m to 1m undulation is visible (Fig. 4). There are smaller structures (1m to 3m wide) visible as well protruding above the surrounding bottom for between 20cm-80cm. These are mussels colonies.

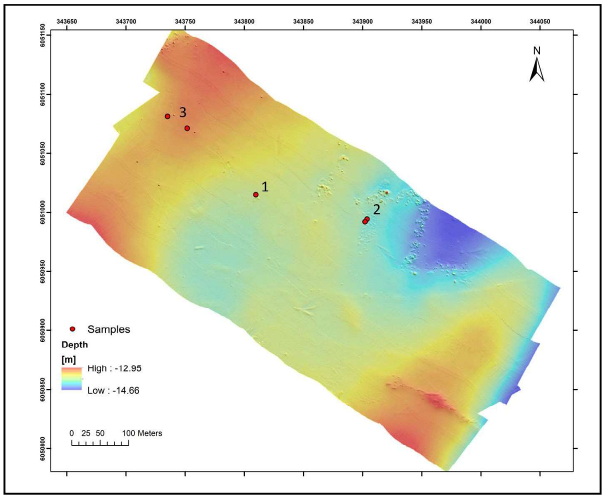

Fig. 4. Bathymetry of the area 2 for 400kHz data and resolution of 25cm. Red points show video and grab sample coordinates. Number represent respective sampling areas.

The backscatter data for both frequencies were created considering the multibeam calibration file, transmission loss and footprint corrections to obtain bottom backscattering strength (BBS) as well as angular backscatter dependance. Snippets allow for high resolution mosaics, limited by physical properties of beams. The higher frequency the narrower is the beam, respectively 0.5°x0.9° for 400kHz and 1°x1.8° for 200kHz.

On the backscatter comparison image (Fig.5.) one can see mosaics from both frequencies draped on bathymetry. Th 200kHz mosaic is 10cm resolution and the 400kHz one is 5cm resolution.

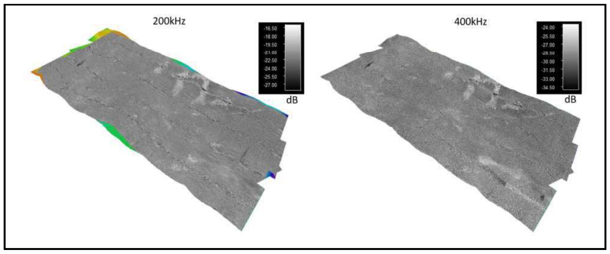

Fig. 5. Mosaics from 200kHz on the left and 400kHz on the right.

The mosaic backscatter range differs between frequencies, for the 200kHz it is -16.5dB to -27dB and for the 400kHz one it is between -24dB to -34.5dB. In average there is a difference of 7dB. One can see it better on the histogram comparison image (Fig.6.).

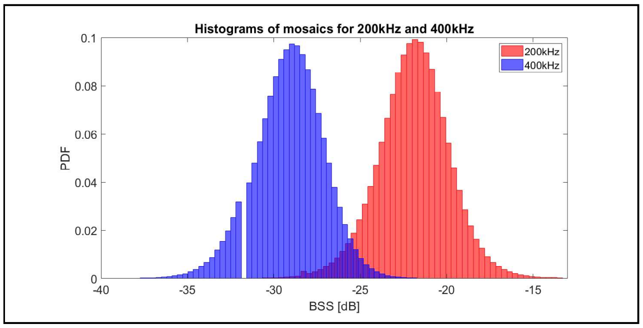

Fig. 6. Histograms of BBS values for both frequenices: 200kHz and 400kHz.

B. *Video and grab samples*

Grab and video samples were collected in tree places around the test area 2 as shown on figure 4. The results of sediment analysis delivered similar seabed characterization between all points. Dominant bottom type is fine sand with median (phi) around 2, which means relatively small grain size, less than 0.24mm.

Video recordings reveal why flat and homogenous bottom shows differences in backscatter. There are mussels colonies spread around the area, most of them visible also on the bathymetry. Darker colors of backscatter are related to weaker signal reflection and brighter to stronger. There are visible bright spots on the mosaics but contrast is better at 200kHz. On the video images it is confirmed the presence of mussels, except the last point (3), where there are mostly dead shells.

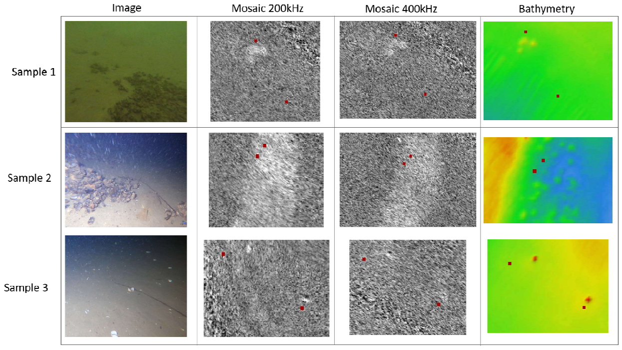

Fig. 7. Comparison of video images, mosaics for both frequencies and bathymetry for 3 sampling areas. The boxes with acoustic data are around 30m wide, the camera image range is smaller (meters).

C. *Classification*

Bathymetry, backscatter and their derivatives are used for segmentation algorithm and later classification procedure that allows assignment of extracted homogenous areas to proper sediment class using ground-truth samples. Unsupervised clustering algorithm from ArcGIS (ISO cluster) was used for final segmentation. Input layers for cluster analysis were: bathymetry, backscatter from 200kH and 400kHz, BPI index of bathymetry, roughness and mean backscatter. An extra layer was created as a pseudo RGB image comprise of 2 backscatter frequencies and bathymetry (Fig.8).

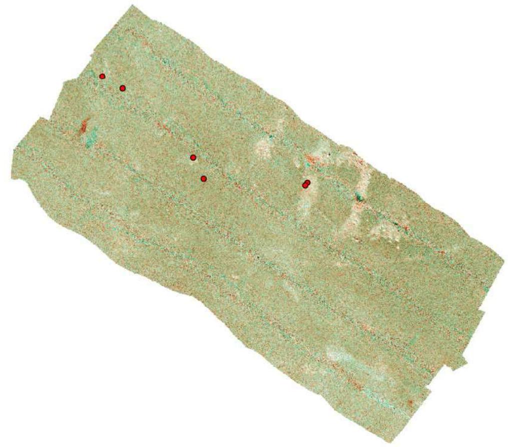

Fig. 8. Pseudo RGB image based on 2 backscatter frequencies and bathymetry. Red dots represent sample areas.

Classification results show 2 classes of benthic habitats: bare bottom and mussels colonies (Fig.9.).

Fig. 9. Classification results representing 2 benthic habitats: bare fine sediment bottom (gray) and mussels colonies (white).

D. *Discussion*

Presented study shows the benefits of using multifrequency approach for habitat mapping. Different frequencies interact in different way with seabed highlighting it's various physical properties. Lower frequency reflects more hardness of seabed while higher can be influenced more by bottom surface roughness. One can observe on figure 5 that for the 200kHz mosaic there is more contrast and backscatter level difference between habitat types, 400kHz image is more homogeneous. It seems that fine sediment dominates inside studied area and the only backscatter deviation comes from mussels colonies. They create large structures and shapes and reflect acoustic signal stronger than background substratum. Mussels are also visible on the bathymetry increasing its roughness, so adding bathymetry to analyzing path increase a discrimination power of the classification algorithm.

Great benefit of NORBIT multibeam was calibrated backscatter hence recording of backscatter strength output. It means that one can compare the data between sites and frequencies obtaining repeatable results. As discussed in Trzcinska *et al.* [3] using calibrated backscatter we can try to identify common acoustic footprint of benthic habitats and limit the number of ground-truth samples that are necessary for proper understanding of our acoustic data content.

There are not too many models describing acoustic reflection from seabed for frequencies >200kHz. There are some studies comparing real data with models [3], [8] and what we observe in this study is in agreement with those conclusions. First of all, relatively higher backscatter responses for softer sediments and lower frequencies has been linked to a stronger volume scattering return [8] what we can observe on figure 6. Fine sediment acoustic response can be within a range of -27dB to -12.5dB for 190kHz [3] which is in a good agreement with our results for 200kHz. There are only a few and various results in the literature related to 400kHz but increasing frequency we always decrease discrimination power and ranges of bottom backscatter values for different sediments start to meet and become ambiguous. That is why it is important to use bathymetry and multispectral backscatter as additional information to increase benthic habitat mapping classification accuracy [9].

Presented results are preliminary, there are still 4 areas that were surveyed with wider frequency range which are not presented here. This is work in progress.

There are still many challenges in tuning backscatter so it is very coupled with sediment physical properties. One of those is standardizing the acquisition and processing parameters of MBES data with multifrequency backscatter investigations. Moreover, with availability of calibrated backscatter data in the future, our ability to monitor and manage marine environments with similar geological and ecological settings will be greatly improved.

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