MULTIBEAM ECHOSOUNDER AS A TOOL FOR COMPLEX MONITORING OF UNDERWATER FACES OF TIDEWATER GLACIERS IN THE ARCTIC

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Abstract: *Glaciers are important indicators of global warming and dynamic environmental change in the Arctic. Their monitoring is crucial for the proper estimation of freshwater discharge to oceans. Tidewater glaciers, those terminating at sea, are far more dynamic compared to their land cousins. They characterize by fast flow at their toe and highly contribute to ice loss through calving and submarine melt. The underwater melting of tidewater glaciers and their evolution on the ocean-ice interface is still difficult to understand because most of the time we are missing a full picture of what is happening underwater.*

Satellites are commonly used for mapping glaciers but they cannot penetrate the water and image submarine glacier faces. Some experiments were done in the past using side-scan sonar for that purpose but the results were not very accurate. Modern multibeam sonars provide high-resolution data but mapping vertical structures is still a difficult task. However, recent developments in underwater acoustics technology allow for overcoming this problem.

Between 2014 and 2018 we conducted 4 expeditions during summer to map glaciers around Hornsund fjord (Svalbard) using NORBIT multibeam sonar. The advanced technology of electronic beam steering of MBES results in the complete mapping of underwater glacier faces from the bottom to the surface in a very efficient way.

In this paper, we present the results of using a high-frequency multibeam echosounder for mapping the geometry of tidewater glaciers face with unprecedented details, together with bathymetry of their basins and detection of sediment plumes and gas seeps in the water column.

Keywords: *Multibeam sonar, glacier, Arctic, bathymetry*

1. INTRODUCTION

Arctic fjords constitute a link between land and ocean. The inshore boundary of a fjord system is usually dominated by the tidewater glaciers and seasonal freshwater input, while its offshore boundary is strongly influenced by oceanic waters. Improved understanding of the fjord-ocean exchange and processes within Arctic fjords is of a highest importance because their response to atmospheric, oceanic and glacial variability provides a key to understand the past and to forecast the future of the Arctic climate. The circumpolar Arctic is the fastest warming region of the planet, and the Svalbard is among the fastest warming regions in the entire Arctic [1].

The submarine melt is an important process at the front of the tidewater glacier. Atlantic waters (AW) carried by the shelf break current along the western Svalbard and entering its fjords are getting warmer. It was recently shown that Atlantic waters (AW) contribute significantly to melting glaciers at the waterlines and subsequent calving of Hornsund glaciers [2]. The freshwater discharge, turbulent mixing and dynamics of the buoyant plume, and the submarine melt rate at the ice–ocean interface are the basic questions related to the tidewater glaciers boundaries processes. Calving of icebergs is also an important component of mass loss from the polar ice sheets and glaciers.

Underwater ice geometry at the front of calving glaciers provides crucial information for understanding calving and melting processes but is difficult to map. So far mostly side-scan sonars were used for remote imaging of the interface of tidewater glaciers but these kind of data cannot give a full picture from the bottom to the top, they just show a general shape of the glacier extent [3, 4]. The multibeam sonar systems are used usually only for seabed mapping of glacial basins [5]. Recent innovation in underwater acoustics and remote sensing devices namely multibeam echosounders (MBES) opened a new possibility to obtain a full picture of underwater ice walls with centimetric resolution. Curved array and active beamforming technology allows for 210° swath or steering the swath focus towards the vertical objects below water. Compact and integrated multibeam sonars can be used nowadays on small boats and be easily mobilised and dismantled.

We present in this paper some results of glaciers mapping and monitoring in Hornsund fjord (Svalbard Archipelago) by means of multibeam echosounder.

2. STUDY SITE AND METHODS

Hornsund is a 34 km long, the southernmost fjord of Spitsbergen located at the western coast (Fig.1). Due to retreat of tidewater glaciers, its area increased from 188 km^2 in 1936 to 303 km^2 in 2010 [6]. In Hornsund there are 15 tidewater glaciers having different characteristics regarding their frontal lengths, bottom depths, and freshwater discharge intensities. Glaciers termini are usually situated within smaller bays, separated from the central part of the fjord by underwater ridges.

The surveys were conducted in summer (usually end of July) in 2014, 2016, 2017 and 2018. The main focus was Hansbreen, the tidewater glacier closest to the Polish Polar Station that was a logistic support for the expeditions.

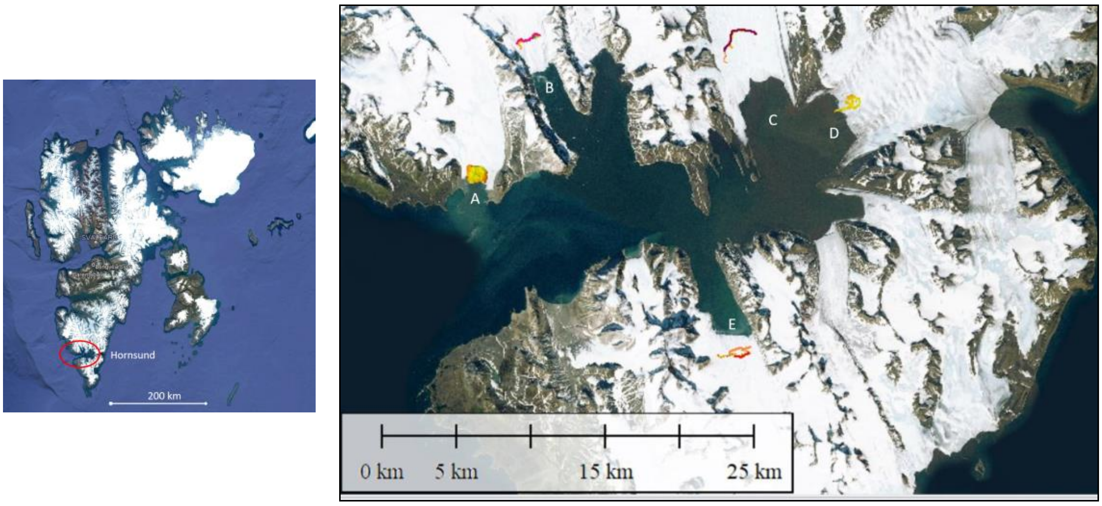

Fig.1: On the left: Svalbard Archipelago with Hornsund fjord indicated (red circle); on the right: Hornsund fjord with glaciers and survey areas (A-Hansbreen, B-Paierlbreen, C-Storbreen, D-Hornbreen, E-Samarinbreen).

3. ACOUSTIC MEASUREMENTS AND PROCESSING

The hydroacoustic survey was conducted from a small, aluminium motorboat (Fig.2). The multibeam was side mounted on the pole together with 2 GNSS Trimble antennas. The multibeam echosounder was NORBIT iWBMS model with 512 true beams, resolution of 0.9°x0.9° per beam and integrated high precision motion unit. The frequency range of the MBES is 200-700kHz but most of the time we used 400kHz and FM pulse with bandwidth 80kHz and 500µs long. In 2017 together with MBES we used also a laser scanner that could map the glacier walls above the water up to 50m.

Fig. 2: The survey boat with the T pole mounting of multibeam echosounder (left) and the MBES attached to the pole (right).

The system setup was done using NORBIT Graphical User Interface (GUI) and QPS QINSy for data collection. Later data were processed in QPS QIMERA where sound velocity profiles can be applied together with local tide provided by the model from the Norwegian Mapping Authority. Data were also cleaned from spikes and artefacts.

4. RESULTS

During 4 research expeditions 5 tidewater glaciers faces and bathymetry of their basins were mapped. Some of them like Hansbreen or Paierlbreen, both close to the Polish Polar Station were mapped couple of times in different years. The deepest registered area was by the Paierlbreen, 160m deep and in 2017 we mapped also the upper part of the glacier face with laser scanner above the water up to 40m. Combining MBES data with laser scanner data we covered the whole hight of the ice wall, around 200m (Fig.3).

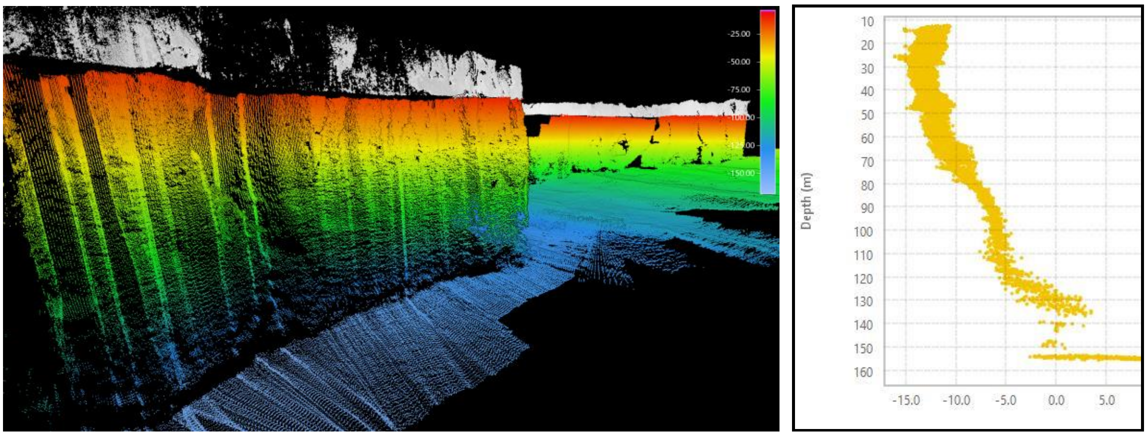

Fig.3: The point cloud data from MBES with colour scale reflecting the depth and white points collected by the laser scanner (left) and the example of the profile of the glacier's wall (right).

The bathymetry of mapped regions helped us to find the range of each glacier, we decided it is a point where the ice cliff is touching the bottom. This way one could compare extent of each tidewater glacier year to year. The only glacier with 4 surveys is Hansbreen, so we are presenting the results of its retreat for the end of July, for years 2014, 2016, 2017 and 2018 (Fig.4).

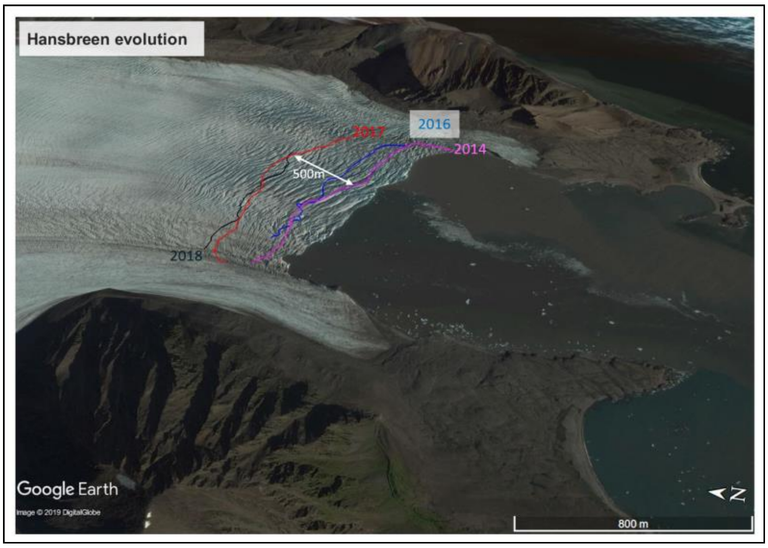

Fig.4: Hansbreen face range for the Summer month (July) measured during 4 surveys: 2014(pink), 2016 (blue), 2017(red) and 2018(black).

5. CONCLUSIONS

Presented results show the efficient methodology of mapping tidewater glacier faces, capturing their 3D shapes and putting them in bathymetric context combining the data from modern multibeam echosounders and laser scanners.

It was possible to map the seabed until 160m depth creating a bathymetry grid of 2m resolution and to show the glacier's face structure under and above water with centimetric resolution. The reflectivity of ice is much stronger than the acoustic response of bottom, especially soft one, so the are still some difficulties to adjust signal strength and dynamics to be able to map both of the areas at the same time. There can be also problems to complete the survey after calving incidents, they are not only dangerous for the boat but also create a lot of growlers that block the navigation.

Multibeam echosounder data can support a monitoring of glaciers retreat and evolution. In our example of Hansbreen we noticed recession of around 500m during 4 years which only proves fast melting processes and extensive calving during Summer seasons and in long term perspective. Observed shapes and profiles of glacier faces revealed terraces, ice foots, undercut notches and other forms of ice cliff morphology. Unprecedented resolution of 3D images of ice walls obtained from MBES brings new knowledge to glaciologists and allows better understanding of calving dynamics.

6. ACKNOWLEDGEMENTS

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