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**NEW METHODS FOR MEASURING ICE RIDGES AND ICE CHANNELS IN FULL
SCALE**

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FOREWORD

In this report no 92, the Winter Navigation Research Board presents the results of a research project on determining ice ridge and brash ice channel profiles using laser scanning and single-beam sonar instruments. Surface features are measured by laser scanning, while submerged parts of the ice features are measured using sonar.

Two ice ridges and one brash ice channel were measured both with the proposed method of using combined laser scanning and sonar and by drilling for validation. The proposed method was found to be significantly faster than drilling and to give promising results. Further development of the measurement method is however needed.

The Winter Navigation Research Board warmly thanks Ms. Annu Oikkonen, Mr. Teemu Heinonen and Mr. Jani Pötrönen for this report.

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W14-10 RidgeChannelSonarLaser

New methods for measuring ice ridges and ice channels in full-scale

Project report

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Introduction

Sea ice ridges are very challenging for winter navigation and offshore activities in ice covered seas, since pressure ridges may reach even ten times higher thickness than initial level ice. In general, it could be said that the ice ridges form the most difficult obstacle for ice-going vessels. Ice ridges are formed under high compression due to wind or currents. Ice floes break when being compressed against each other and ice ridge grows as broken ice blocks pile up below and above water level. In the Baltic Sea there have been recordings of ice ridges with total thickness exceeding 30 meters and ridge keels (submerged portion of ice ridge, Figure 1) reaching the depth of more than 28 meters. Even thicker ridges are observed in the Arctic Ocean, where maximum keel depth recorded is even over 45 meters.

Usually the cross-section of a pressure ridge keel has a triangular shape (Figure 1). However, the shape of ice ridges varies widely depending on initial conditions (level ice thickness, compression, etc.) and the age of the ice ridge (slope angles decrease by time). Most of the total volume of an ice ridge is submerged, and based on the visible part, a sail, a reliable estimation of ice ridge thickness nor width cannot be made. Therefore, measurements covering the submerged portion of the ice ridge, a keel, are necessary. Usually this is done by drilling, which can be very arduous in the case of a thick ice ridge. In order to cover reliably the whole cross-sectional profile, numerous drill holes are needed. However, a significant advantage of drilling method is the possibility to record the inner structure of the ice ridge (fraction of voids).

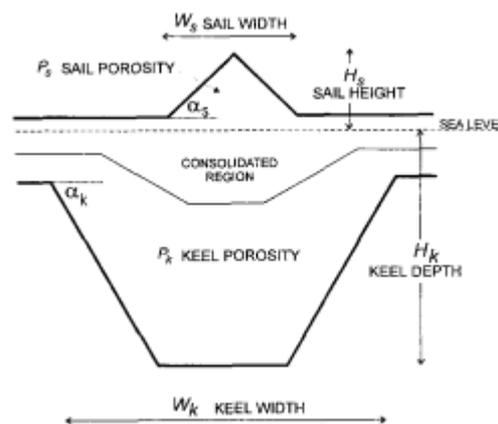


Figure 1. Schematic illustration of the typical first-year sea ice ridge (from Timco and Burden, 1997: An analysis of the shapes of sea ice ridges).

Another topic of interest is the thickness profile of a brash ice channel as the majority of the merchant shipping takes place in brash ice channels. The geometry of a brash ice channel is important factor for the ships ice channel resistance, and for example the engine power regulations of Finnish-Swedish ice class rules are based on the geometry of the channel. The thickness profile of a frequently opened ship channel shows typically thickened areas close to channel walls and thinner region in the center of the channel (Figure 2). In addition, there may be significant volume of ice blocks invisible, underneath the level ice in the side of the channel. Frequent ice breaking increases the total ice volume considerably. The thickness profiles of brash ice channels are also measured usually by drilling, similarly to ice ridges. This can be somewhat inaccurate due to loose ice blocks and also hazardous depending on the level of freezing in the channel.

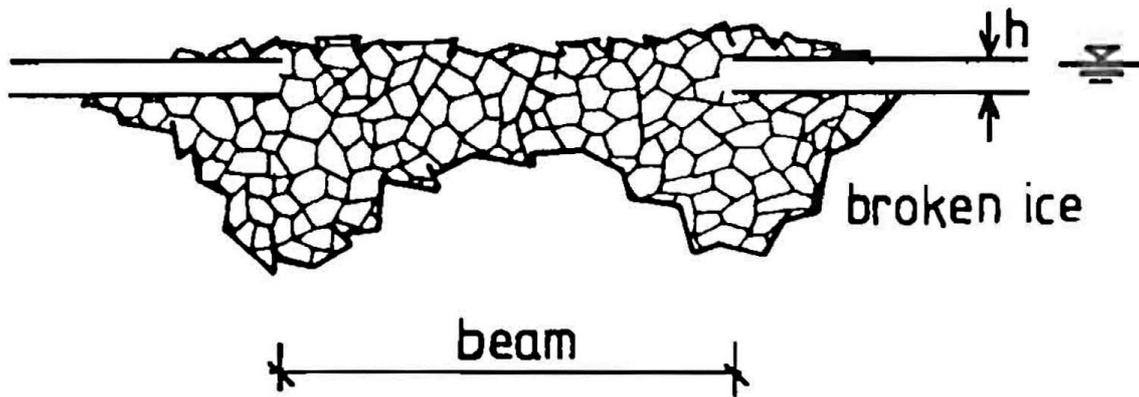


Figure 2: A schematic picture of a brash ice channel (from Sandkvist, 1978: Problems in keeping a year-round navigation in Luleå harbor).

The goal of this project is to test and evaluate the applicability of a new method for profiling ice formations (ridges and brash ice channels). The new method combines laser scanning and mechanically scanning single-beam sonar instruments. Laser scanning has been shown to measure very accurately the top surface of dry snow and ice cover and nowadays lasers are regularly used for sea ice research. Different kind of sonar instruments have been used for detection of underwater portion of ice cover, but the use of sonar techniques for ice ridge measurements is not as unambiguous as laser scanning of top surface. Ice ridges keel is formed of ice blocks piled up under high compression, and the combination of arbitrary orientated ice blocks and voids causes lot of multiple reflections of sound pulses and noise for sonar equipment. In this study, a mechanically scanning single-beam sonar is used. Disturbances caused by the very high roughness of the surface (i.e. ice blocks) are assumed to decrease significantly when using mechanically scanning single-beam sonar instead of multi-beam or side scanning sonars. The evaluation of this method is done by comparing the results with measurements made by drilling.

This is a joint research project of Aker Arctic Technology Inc and Meritaito. The field measurements were carried out in the Bay of Bothnia during 17. – 21.2.2014. Project is funded by Winter Navigation Research Board.

Measurements

All data was collected during the field campaign 17.-21.2.2014 in the Bay of Bothnia. During the campaign the objective was to profile two ice ridges and a brash ice channel. Two ice ridges measured were chosen to represent very different dimensions. Another important factor for measurement site selection was the accessibility with a hovercraft from the base of Meritaito in Martinniemi. Measurement sites are shown in Figure 3.

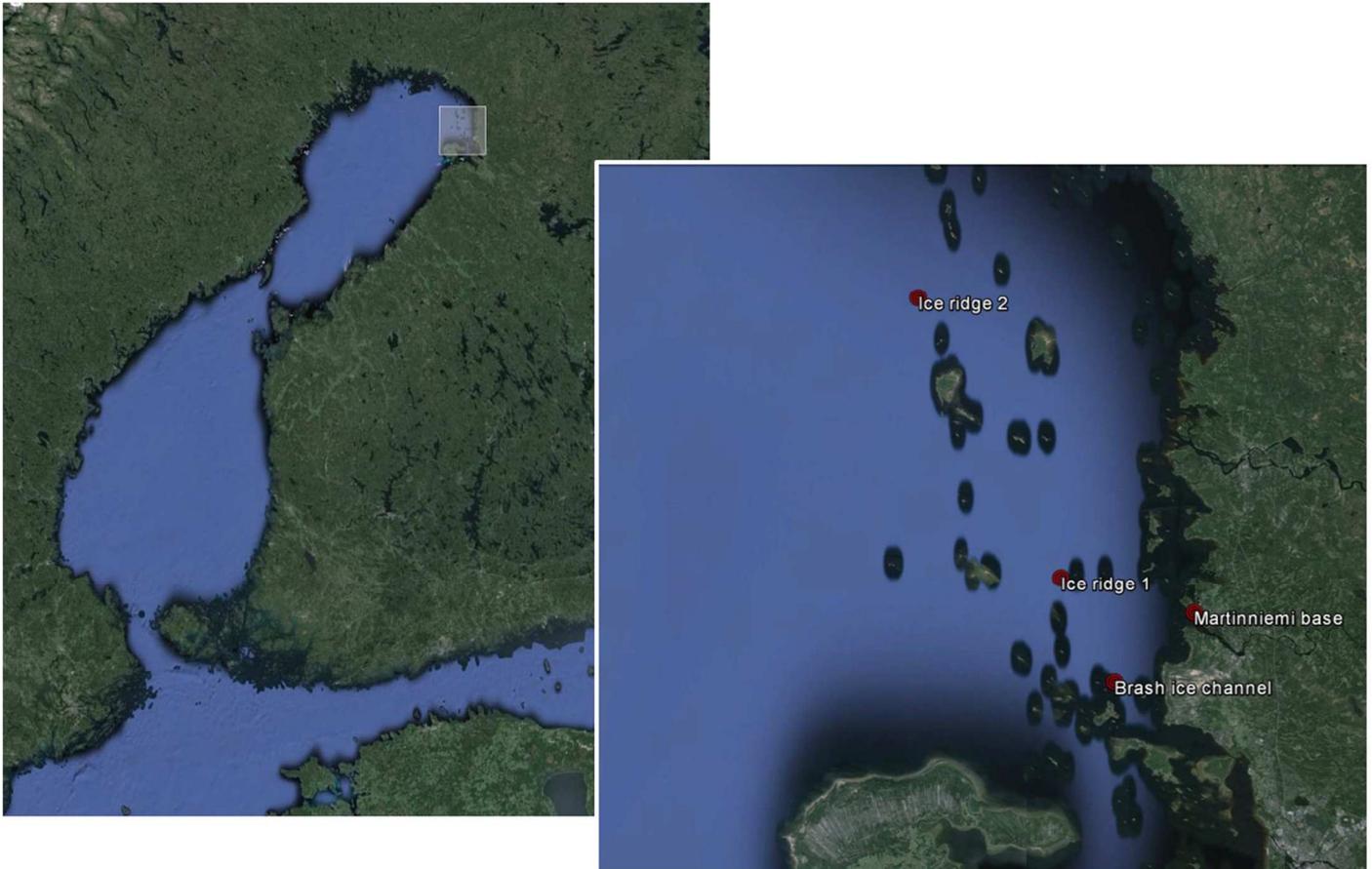


Figure 3. Locations of the measurement sites.

Ice ridges were measured by drilling and with scanning sonar and laser in order to compare the results and evaluate the feasibility of the new method. The campaign started with the ice ridge measurements because they were assumed to provide better first hand estimation about the applicability of scanning sonar and also show possible needs for immediate improvements.

Drill hole thickness and freeboard measurements

Drilling of the ice ridge was conducted along transverse line of the ridge to gain a cross-sectional profile. Measurement interval along the transect has to be small enough to capture the shape of the keel. On the other hand, smaller interval leads to higher number of drill holes, and thus to a longer measuring time. For the ice ridge 1, a rather small ridge, the interval of 1 meter was used over the level ice around the sail, and interval was set to 0.5 m over the ridge sail/keel in order to catch the shape of sloping surfaces more precisely. The ice ridge 2 was so wide and thick, that the measurement interval had to be decided based on the time available for measurement, and therefore the drill hole measurements of the ridge 2 were conducted with interval of 2 m.

The drilling is performed with a power auger with drill extensions (length one meter) which are added one by one as the drilling progresses in depth (Figure 4). Ice ridges consist of ice blocks and voids and in addition the strength of the ice can vary through the thickness from hard ice to slushy layers. Voids are detected as the drill drops lower and soft ice is determined both by the resistance felt by the driller and drilling speed. These three different layers (hard ice, soft ice and void) were chosen to represent the internal structure.



Figure 4: Measuring the ridge by drilling. One person is doing the drilling while the other is observing where voids etc. are located.

Freeboard was determined with a beeper attached to a measure. The beeper gives a sound when being in contact with salt water. Beeper was lowered into the drill hole until it reached the water, and the distance to the top surface of ice was recorded.

Drilling method can be stated very accurate for level ice, when the bottom surface is easily reached with a measure. However, for the ice ridges, the accuracy is lower because of the difficulty of determining the bottom surface. For thick ice ridges, the bottom cannot be unambiguously detected with a measure and the thickness is most often recorded based on the length of the drill needed to reach the ice – water interphase.

As explained above, ice ridges consists of ice blocks and voids, and sometimes an empty space between ice blocks can be meters. During the drilling, once there is no more ice found with the present drill length, general practice is to add one more extension to test whether the observed ice – water surface is the top of the void or the bottom of the ice ridge. Usually the drill extensions are about one meter long. This means that a void with thickness more than a meter may be mistakenly recorded as the bottom of the ice formation.

In addition, the ice blocks can be very loosely together at the deepest parts of the keel and the drill only moves the ice blocks instead of drilling through them. This is often felt as a low resistance for the drill (which is interpreted as soft) and there is no clear boundary between ice and water found.

Laser scanning

Laser scanner is a state-of-art survey tool to collect three-dimensional point information from the chosen object. The purpose of a 3D scanner is usually to create a point cloud of geometric samples on the surface of the subject. 3D scanners share several traits with cameras. Like cameras, they have a cone-like field of view, and like cameras, they can only collect information about surfaces that are not obscured. While a camera collects color information about surfaces within its field of view, a 3D scanner collects distance information about surfaces within its field of view. The "picture" produced by a 3D scanner describes the distance to a surface at each point in the picture. This allows the three dimensional position of each point in the picture to be identified.

In this project 3D laser scanner was used from a static tripod to collect a point cloud of snow/ice surface (Figure 5). Prisms were used to register point clouds when several tripod locations were used to build a complete model of area of interest. Corresponding profile information to drilling was then extracted from the point cloud.

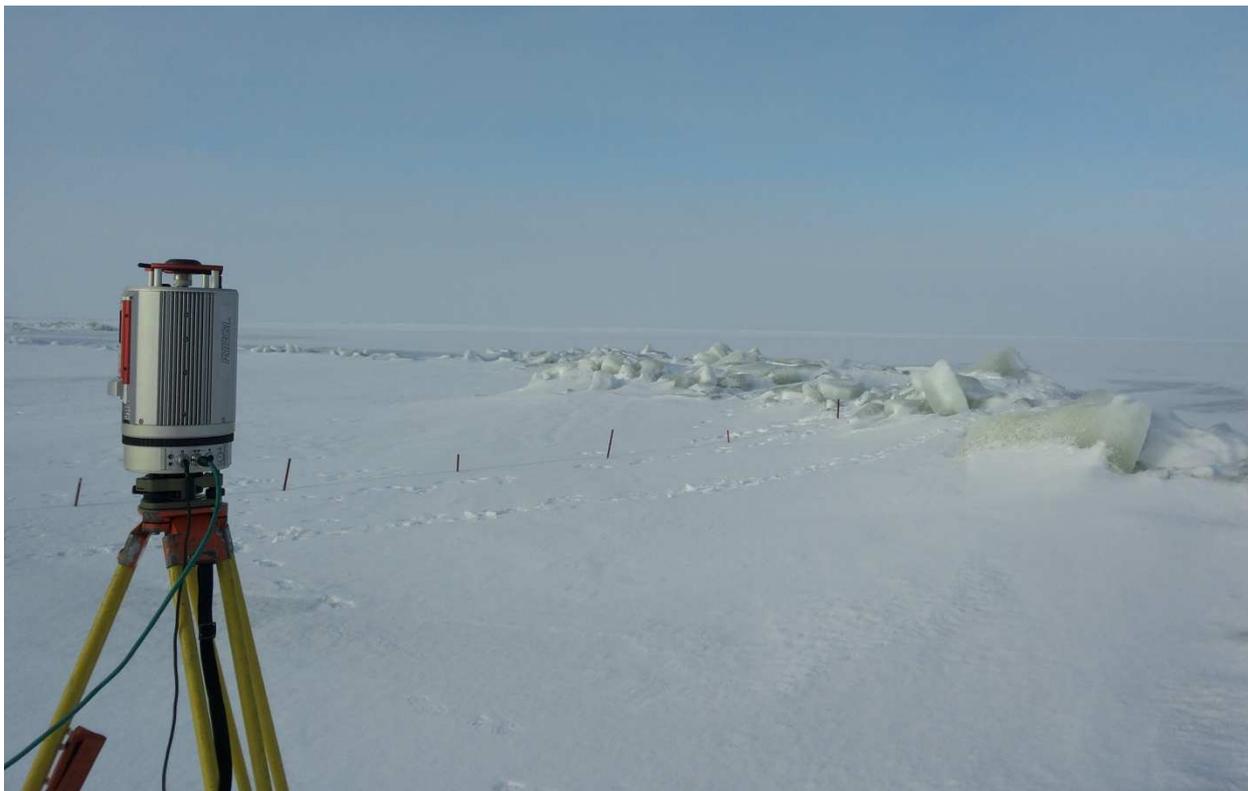


Figure 5. Laser scanner on tripod in front of the ice ridge.

Scanning sonar

Single-beam sonars use a single transducer to transmit and receive acoustic energy signals. Mechanically scanning single-beam sonars are used for various underwater applications, especially small-scale inspections. In this project mechanically scanning single-beam sonar with profiling and imaging option was used. Imaging sonar is primarily used for visual interpretation and uses a fan-shaped acoustic beam to scan a specified area or target. Profiling sonar is primarily

used for quantitative measurements where a narrow, conically shaped beam generates a single point for each ping.

In this pilot project, the scanning sonar was attached to a bar. A hole was cut into the level ice for appropriate distance from the ridge and the sonar was lowered into the water and the bar was fixed to ice surface (Figure 6).

As for all acoustic sonar systems also for the scanning sonar the temperature and the salinity of water needs to be known to determine the speed of sound in the water column. This was done with thermometer from each site while the salinity was known by the practice.

As the measurements with both scanning sonar and laser are made statically, there are no inaccuracies caused by movements of the measurement platform (contrary to measurements made from moving platform, i.e. laser in aircraft, sonar in submarine). This enables nearly immediate utilization of data, when the amount of necessary afterward analyses is minimized.



Figure 6. Lowering of the scanning sonar under the level ice in front of the ice ridge.



Figure 7. Online view from the scanning sonar software during the measurement.

Results

Ice ridge 1

The measurements started with the selection of profile transect of the ice ridge, and the measurement line was marked with sticks with one meter interval on level ice and 0.5 m interval on the visibly deformed area. Drilling and laser scanning were conducted simultaneously, and sonar scanning after the drilling was finished. Sonar scanning was made from both sides of the ridge, from the distance of about 10 meters from the top of the sail. Scanning sonar was lowered to the depth of 5.7 meters.



Figure 8. Ice ridge 1.

The scanning sonar image of ice ridge 1 is shown in Figure 9. White dots are the points from where the profile figures has been created and are collected with profiling mode. Pink color in the imaging mode sonar image marks the area from where the sonar has received very strong echo while from other areas response has been weaker.

Comparison of the measurement results from drilling and sonar and laser scanning is shown in Figure 10. Overall, the results are fairly well compatible. The top surface profile obtained from laser scanning (blue dashed line in Figure 10) shows the top of the snow layer while the drilling measurements include ice only.

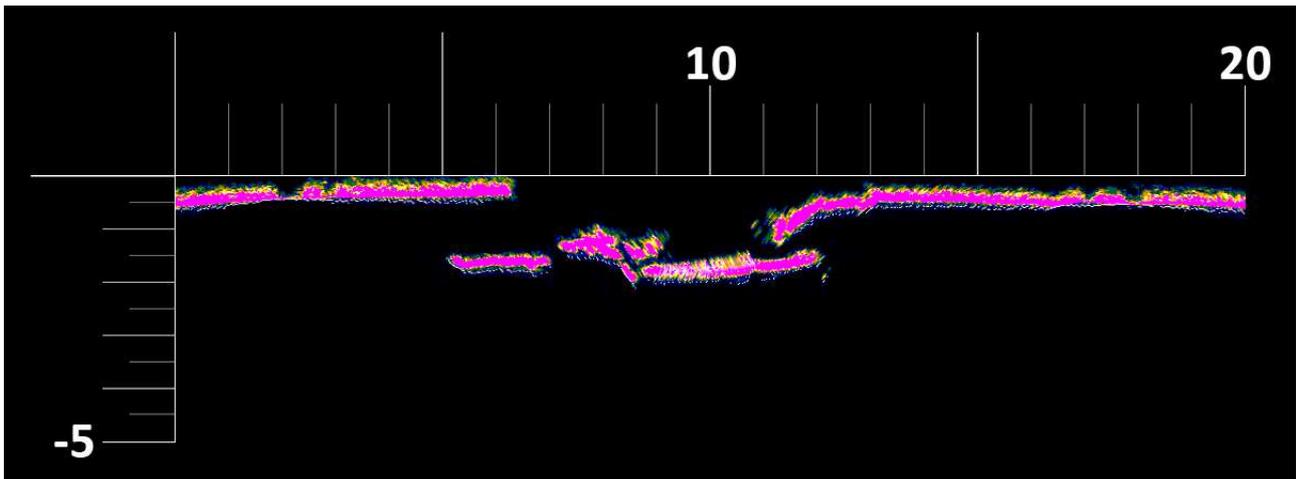


Figure 9. Scanning sonar image of the ice ridge.

The most prominent difference between drilling and scanning sonar results can be seen in the area where the deepest keel was recorded by drilling, at the location of 10-11 m in the measurement line. The maximum sail height (61 cm of ice) was observed at 10.5 m, supporting the maximum keel depth location observed by drilling. The discrepancy between two methods may result from the order in which the measurements were made. The scanning sonar measurements were conducted after the drilling. Drilling may cause changes in the shape of the keel when some unconsolidated ice blocks in the bottom of the keel may be pushed to the side. During the drilling, at the locations from 10 to 11 m, a void near the bottom of the keel was observed with some ice blocks or soft ice underneath it (Figure 10). The very steep keel shape recorded in drilling may have changed to more smooth profile corresponding to the shape recorded later by scanning sonar.

Sonar profiling was made from both sides of the ridge and the profiling ranges overlap at the location 10.5m. At this location, two sonar measurements show about 20 cm difference in keel depth, providing an estimate of the accuracy of the method. Part of the difference can be caused by the roughness of the keel surface at overlapping area. Minor angular disorientation of the sonar head, which is difficult to control at the site, can also cause difference at working range of around 10 m.

The comparison of individual drilling results with scanning sonar recordings is not relevant since the positions are not exactly overlapping. Therefore, the comparison between scanning sonar and drilling results is made using the recorded cross-sectional area of the keel. For the ice ridge 1, cross-sectional keel area measured by scanning sonar is 14.0 m² while drilling gave a keel area of 12.4 m², i.e. 11% lower.

As described in the measurements section, the drilling may sometimes lead to an underestimation of the total thickness, if a void is mistakenly recorded as the bottom of the ice formation. This was clearly shown during the measurements of the ice ridge 1. Ice drilling was conducted before the sonar scanning. At the location 6.5 m, the drilling result was recorded as level ice with the thickness of 50 cm. This recording was based on the normal practice of adding one more extension after reaching an ice – water interphase. Later, scanning sonar showed ice in the depth of nearly 2 meters in the same location. Ice drilling result was checked with longer drill, and the sonar recording was verified.

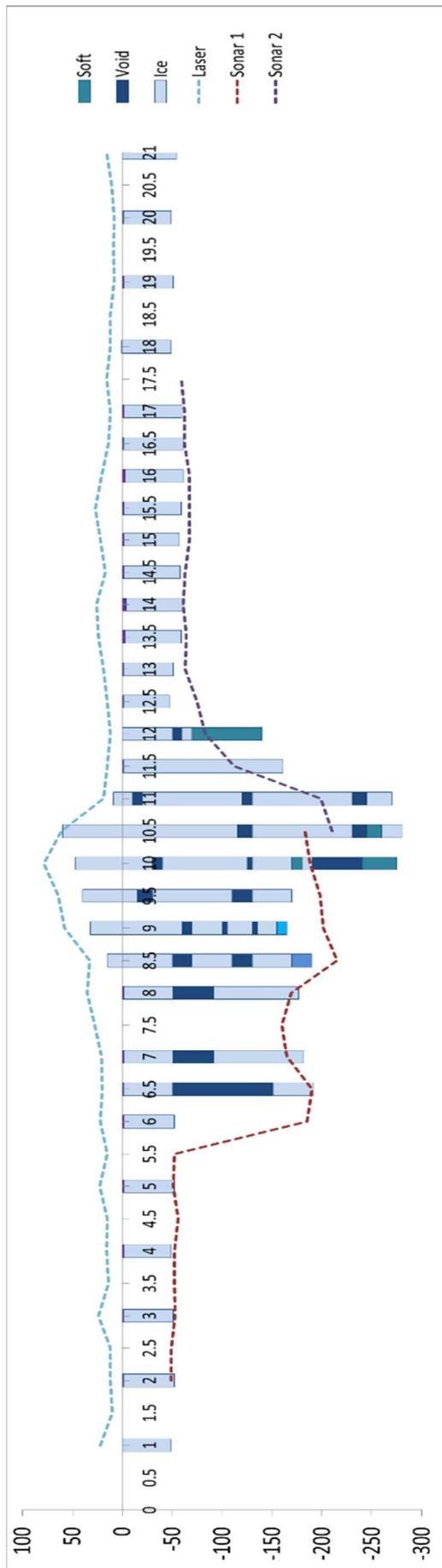


Figure 10. Results from drilling (bars), laser (top surface, blue dashed line) and sonar (bottom surface, red and purple dashed line) profiling of the ice ridge No. 1. The x-axis in meters while the y-axis in centimeters.

Ice ridge 2

For the ice ridge 2, the scanning sonar measurements were decided to be performed first in order to avoid possible changes in the shape of the keel due to drilling. Also the snow thickness was measured this time. The ice ridge 2 (Figure 11) was significantly wider and thicker than the ice ridge 1 and the importance of sufficient depth of the sonar instrument was clearly shown. After modifications of the lowering bar, the maximum depth of the instrument was 10.1 meters, about 4.5 meters lower than during the measurements of the ice ridge 1. However, still greater depth would have been necessary to increase the quality of the scanning sonar result near the deepest parts of the keel.



Figure 11. Ice ridge 2.

As Figure 12 shows, the keel is well detected until the depth of 7 meters (to the distance of about 10 meters along measurement line). Drilling results showed that the maximum thickness of the keel was over 10 meters, i.e. keel reached even below the level of the sonar. Therefore closer parts of the keel made it impossible to measure the deepest parts reliably by forming a mask in front of it. It can be also seen from the figures below, that the sonar detects nicely all the surfaces against it but the keel bottom which is around the same depth as the sonar head is acoustically challenging. As described earlier, the used sonar equipment works in two different modes. The imaging mode, presented in Figure 12, shows that more information is available than the profiling mode (Figure 13) can offer.

The ice ridge 2 was recorded with scanning sonar from one side only. On the other side of the ridge, it was impossible to find a suitable and safe location for lowering the instrument, since there were big ice blocks under the level ice still over 20 m distance from the visible sail of the ice ridge.

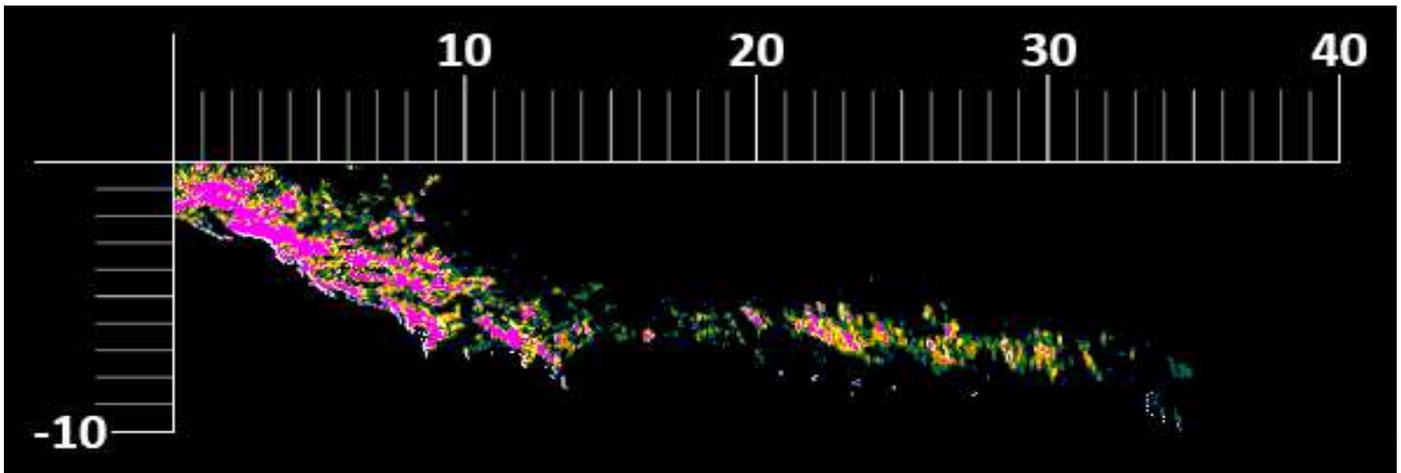


Figure 12. Sonar scanner plot of the ice ridge No. 2.

In the parts of the transect where the sonar was able to capture the bottom of the ice keel, the correspondence with drilling results is good (Figure 13). In the scanning sonar image (Figure 12) especially the part from 5 to 10 m corresponds to drilling observations about weaker layers at the bottom of the keel. The most prominent difference between the methods is observed at the distance of 7 meters, where the sonar showed strong indications of ice in the depth of over 5 meters while drilling recording was only 1.7 meters. On the other hand, in the previous and following measurement points, the recordings from two methods are in good agreement. As described earlier, it is possible that a very large void has been mistakenly considered as the water layer under the keel.

For the ice ridge 2, the comparison of scanning sonar and drill hole results using the area of cross-sectional profile is not as straightforward as for the ice ridge 1. The area covered reliably with both method is very limited and the result depends significantly on the determination of the borders of the area.

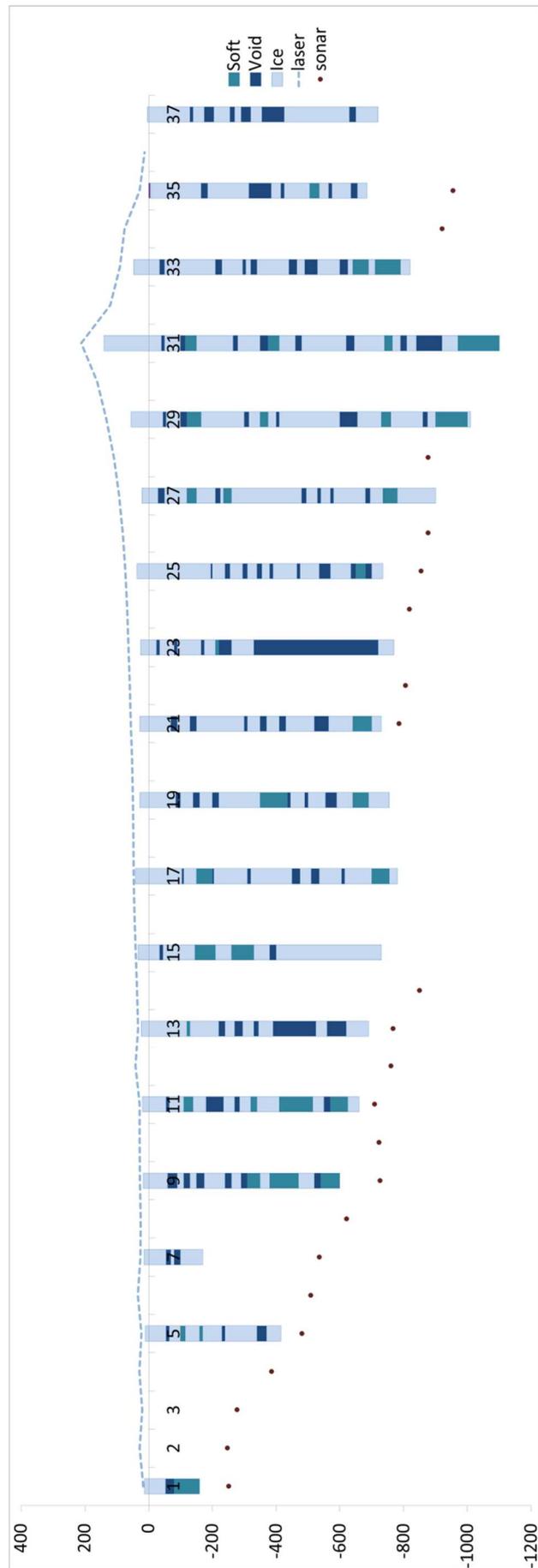


Figure 13. Results from drilling (bars), laser (top surface, blue dashed line) and sonar (bottom surface, red dots) profiling of the ice ridge No. 2. The x-axis in meters while the y-axis in centimeters.

Brash ice channel

The brash ice channel was planned to be measured similarly to ice ridges, i.e. with scanning sonar and laser and by drilling. Unfortunately, measurements were limited only to laser and sonar, and those from one side of the channel only. After first sonar scanning, a ship sailed in the channel, and drilling and crossing the channel was considered too dangerous.

However, the scanning sonar and laser results show expected profile of the brash ice in channel, although the profile was achieved from one side only (Figure 14 and Figure 15). Based on the results from ice ridges1 and 2, it can be assumed that the thickening of ice starting at the distance of about 7.5m from the sonar is real. There is a steep slope beginning at the location of about 8 m, when the thickness increases nearly 1.5 meters over the distance of 2 meters. The thickening of underwater portion of the brash ice begins already at the location where there is level ice on the top, corresponding well with typical brash ice channel profile (Figure 2).

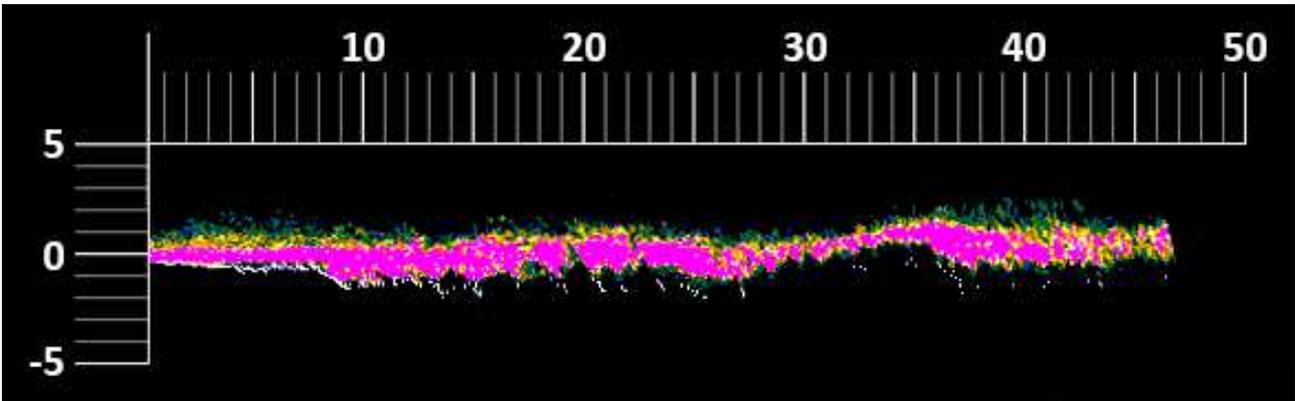


Figure 14. Sonar scanner plot of the ship channel.

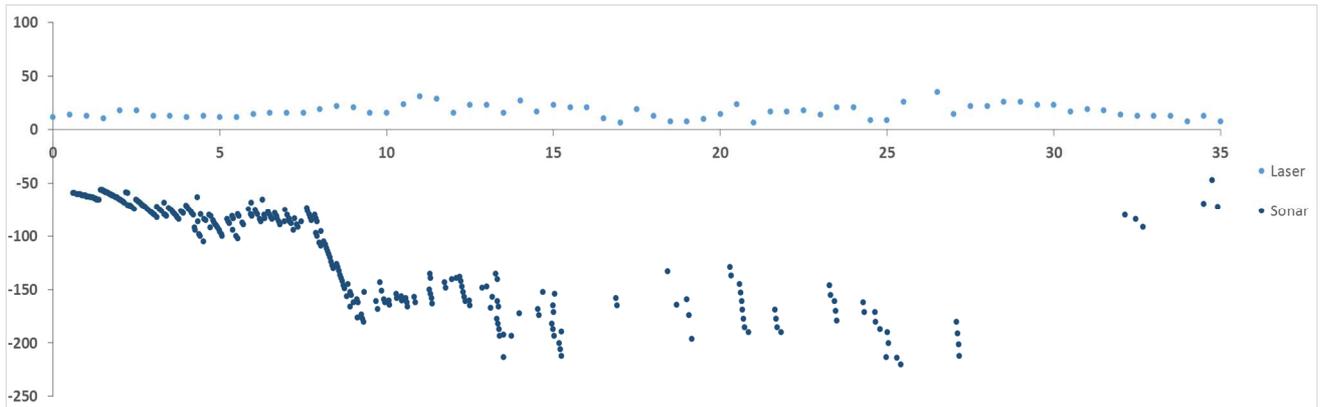


Figure 15. Profile of the brash ice channel obtained with laser scanner (light blue) and scanning sonar (dark blue) from one side of the channel (location 0 m). The x-axis in meters while the y-axis in centimeters.

Discussion and conclusions

In general, the results of the new method correspond fairly well with the results obtained by drilling of the ridges. The scanning sonar showed its applicability in recording the bottom profile of ice formations. However, the measurement practice needs still further modifications before wider use.

The measurement campaign showed that the clear advantage of the new method is the much shorter measurement time. Scanning sonar provides a good, instant overview of the ice formation, since the first plot on the field gives already a lot of information. In order to gain a reliable profile of an ice ridge, drilling has to be made with short interval along cross section, which leads to numerous drill holes.

Drilling method has also several inaccuracies such as the difficulty of defining the exact bottom of the thick keel. The advantage of sonar and correspondingly the disadvantage of drilling method was shown, when the sonar captured ice blocks underneath the level ice, which were not observed in ice drilling.

Advantage of the drilling method is the gained information about the internal structure of the ice formation. Measurements with laser and sonar determines only the location of top and bottom surfaces of the ice ridge, but by drilling the fraction of voids i.e. the amount of ice can be estimated. Also, there can be situations when the underwater parts of the ridge block the sonars view and it is possible to make false assumptions of the keel geometry, e.g. if there would be two keels for the ridge.

For scanning sonar it is important to lower the instrument to sufficient depth, as the results of the ice ridge 2 show (Figure 12 & Figure 13). During this campaign, the maximum possible depth was about 10 meters, but even greater depth would have been necessary in order to record the deepest parts of the keel.

In addition, finding a suitable position to lower the sonar can be problematic, especially when measuring a large ridge formation. The ice can be rafted already far away from the sail and deepest parts of the keel and the rafted ice makes it impossible to cut a hole for the sonar at least with a chainsaw.

Since the ice ridge measurements show the applicability of the scanning sonar for ice mass detection, it can be assumed that the profile obtained in the brash ice channel is also realistic. Unfortunately, during this campaign the measurements of the brash ice channel could not be conducted as planned and the data collected is not sufficient for deeper analysis and conclusions. Scanning sonar has lot of potential on improving the brash ice channel measurement methods and therefore further studies would be very valuable.