Suominen, Mikko; Polojärvi, Arttu; Oikkonen, Annu

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Ridge Profile Measurements for Understanding Ridge Resistance

Mikko Suominen[1], Arttu Polojärvi[1], Annu Oikkonen[2]
[1] Aalto University, Department of Mechanical Engineering, Espoo, Finland
[2] Finnish Meteorological Institute, Helsinki, Finland

ABSTRACT

Ice ridges are the most difficult ice features that ships encounter in first-year ice conditions. Our understanding on ridge resistance on ships is currently limited, but we can assume that the keel of a ridge can have a significant impact to the resistance due to its large volume. In order to study the ridge resistance, we measured ridge profiles and recorded ship machinery and operational data during RV Aranda sea ice cruise in the Baltic Sea on spring 2016. This paper presents results from our ridge profile measurements made by drilling and with a sonar. We found a fairly good correspondence between these two methods. The maximum depth of the profiled ridges varied between 3 and 5 meters and the width of the cross sections from 10 to 25 meters.

KEY WORDS: Ridge profile; Drilling; Sonar; Ridge keel; Ridge sail.

INTRODUCTION

The ships are forced to navigate through the ice fields independently or in the assistance of ice breakers. In the first-year ice conditions, the thickness of the level ice is limited, but it can increase mechanically in a short time through ridge formation. Ridge formation leads to deformed ice features that may be even tens of meters thick (Timco and Burden, 1997; Strub-Klein and Sudom, 2012). Figure 1 illustrates how the first-year ridges consist of a sail, a refrozen consolidated layer, which is commonly thicker than the surrounding level ice (Kankaanpää, 1991; Veitch et al., 1991), and a keel, which can be very large in volume. Ridge properties and resistance are of interest, as the ridges are the most difficult ice features ships encounter in the first-year ice conditions.

In order to study the ridge resistance, a group of researchers participated to the Sea Ice cruise on board RV Aranda in March 2016. Extensive measurement campaign included, for example, surface laser profiling, electromagnetic measurements (EM), recording of ship machinery and navigational data, visual observations, ridge profiling, and snow thickness measurements. The profiles of six ridges were determined by drilling and with a sonar. After the ridge was profiled, the ship penetrated the ridge while the navigational and machinery data were recorded with high frequency. Machinery data enables the estimates of the used thrust, which together with measurements on the speed and location of the vessel with a differential GPS, allows the identification of the increased resistance due to the ridge.

In this paper we present the results from the ridge profiling measurements by drilling together with some of the results from the sonar measurements. While this data is beneficial for our future ridge resistance study, it can be also used in such transit, or ice mechanics, simulations as presented in Kuuliala et al. (2017), Polojärvi and Tuhkuri (2009; 2013) or Gong et al. (2017). We start the paper by introducing our measurements, and then proceed by describing the research voyage. After this, we introduce and briefly discuss our results before concluding the paper.

METHODS

Ridge Profiling by Drilling

We first measured the ridge thickness and profile using a standard way of profiling by drilling. When the drill head first goes through the level ice, the length of the drill inside of the level ice is measured. This gives the thickness of the ice. In a case of ridge keel, there are pores between the ice blocks that form the keel as Figure 1 illustrates. When the drill head goes through an ice block, the length of the drill inside the ice is again written down. Then the drill is pushed downwards to test for additional ice blocks under the most recent block that was drilled through. If an additional ice block is found, the drilling is continued. We continued drilling until we could not find additional blocks for, at least, 1 meter distance. The depth, where the drill went through the ice for the last time, was defined to be the depth of the keel at that point. For all profiled ridges, several boreholes in well-defined drill lines were used to measure the overall geometry of the ridge.

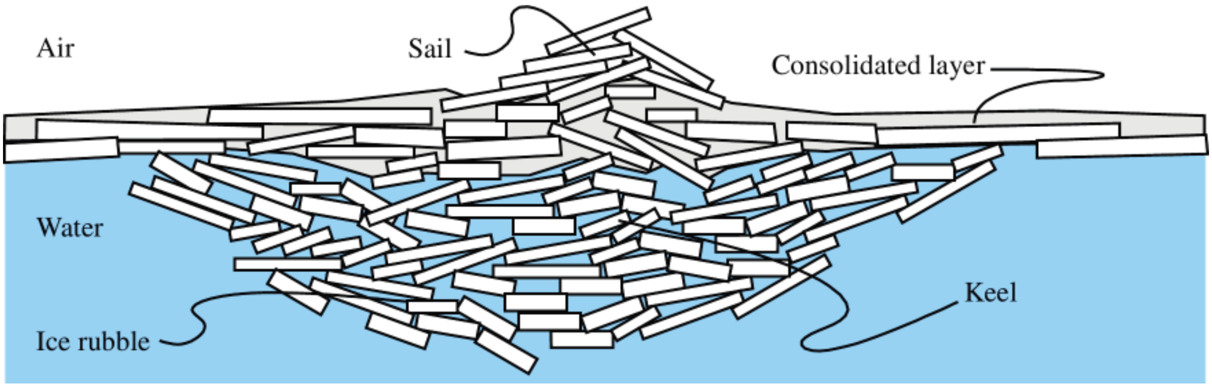

Figure 1. Cross section of a ridge with its main parts indicated: The sail above the waterline and the keel underwater. The keel comprises of a consolidated layer close to the waterline and the unconsolidated, or partly consolidated, ice rubble (Polojärvi, 2013).

Ridge Profiling using Sonar

The sonar head employed in the measurements was a Kongsberg 1071 series high resolution single-beam scanning sonar. The sonar enables imaging and profiling the keels even if not purposely built for it. The measurements were recorded and initially processed with Kongsberg MS 1000 software. The software records the distance of the sonar head from the echoes coming from ice for producing two type of results: (1) a cloud of data points describing the keel profile, and (2) a sonar image that can be used in the profiling.

The measurement of the distance with a sonar is based on the speed of the sound, which has to be determined. Here the water was estimated to be 1°C in temperature, the salinity was measured to be 3 ppt, and the average depth for the sonar head 3 meters. These were used as an input in the software, which gave the sound speed of 1411 m/s. The employed sonar head allows the use of a fan or cone-shaped beams. As the cone beam produces less noise in the measurements, it was deemed better and used in the measurements.

With the cone, two scanning frequencies, 900 and 1200 Hz, were allowed. Figure 2 presents example images from the sonar measurements with these frequencies used. As can be seen from Figure 2, the higher frequency produces considerably less background noise to the measurements. The images were processed using MATLAB. In brief, standard MATLAB image processing functions were used to first convert the original images to binary images shown in Figure 3. The binary images allowed us to simply scale the images (from image coordinates to the one used in the field) and to detect the features from them. These properties allowed a straightforward way of using the sonar images for verification and as a support for interpreting the sonar data.

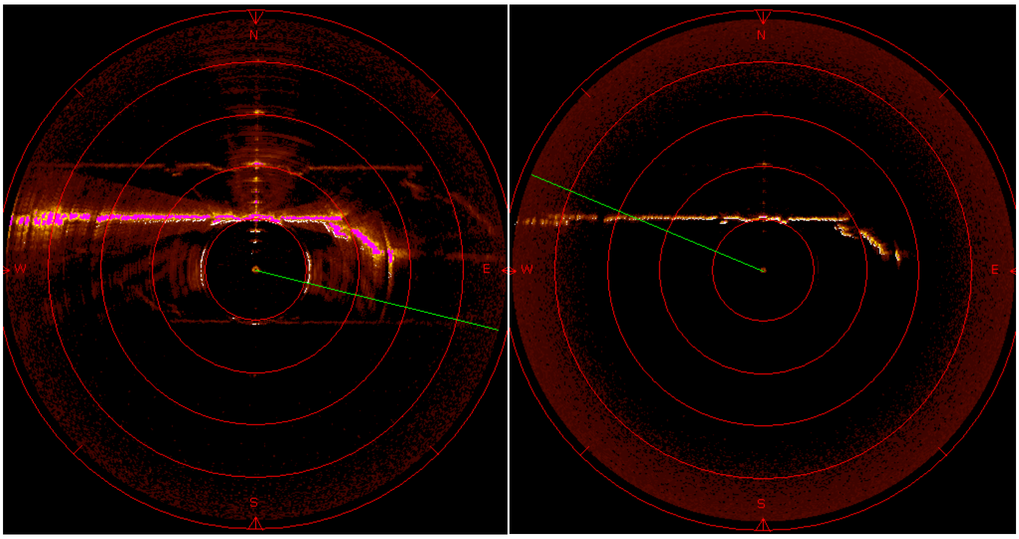

Figure 2. Raw images from the sonar measurements with a frequency of 900 Hz (left) and 1200 Hz (right) measured at the center line (CL) of ice station IS5. The circles indicate the distances from the sonar head with five-meter range.

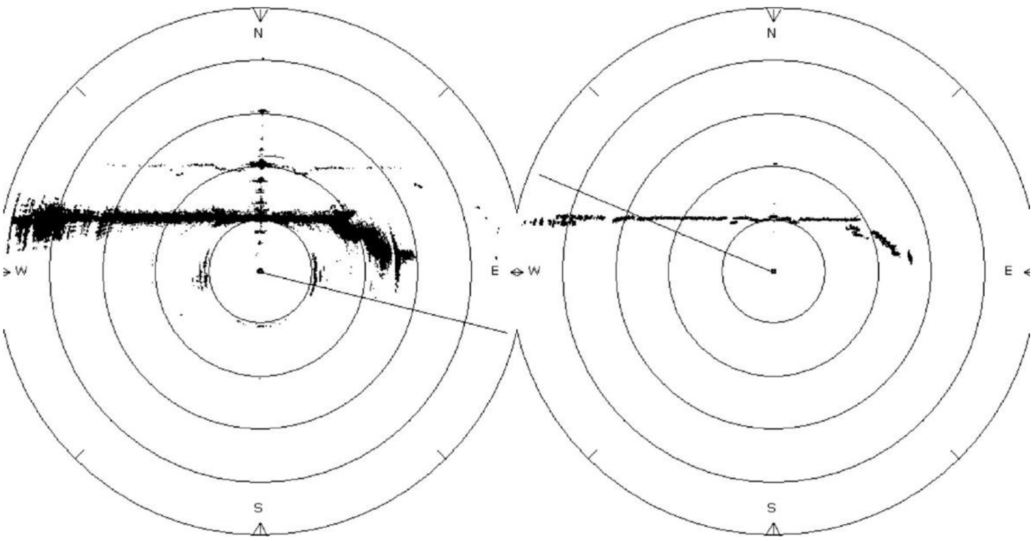

Figure 3. The binary images created from the sonar produced images of Figure 2. These images were created using standard MATLAB image processing functions for further processing of sonar data. The colors of the figures are here inverted.

DESCRIPTION OF THE VOYAGE

The voyage launched from Helsinki on February 29, 2016. Figure 4 presents the ship route during the expedition, and the general ice conditions in the Baltic Sea during the voyage. Due to the mild winter, sea ice existed only in the Northern part of the Baltic Sea, and thus the expedition headed to Bothnian Bay. The first ice was encountered near Tankar lighthouse (63.95° N, 22.85° E) on March 1. Some measurements were conducted in the early morning of March 2, after which the ship headed towards Oulu for researcher and crew exchange, and arrived there on March 3. The ice conditions were initially easy, but the severity of the conditions increased towards the north as the thickness and deformation level of the ice increased. The ship got stuck few times and had to ram through the heavier deformations, and circle around the heaviest conditions.

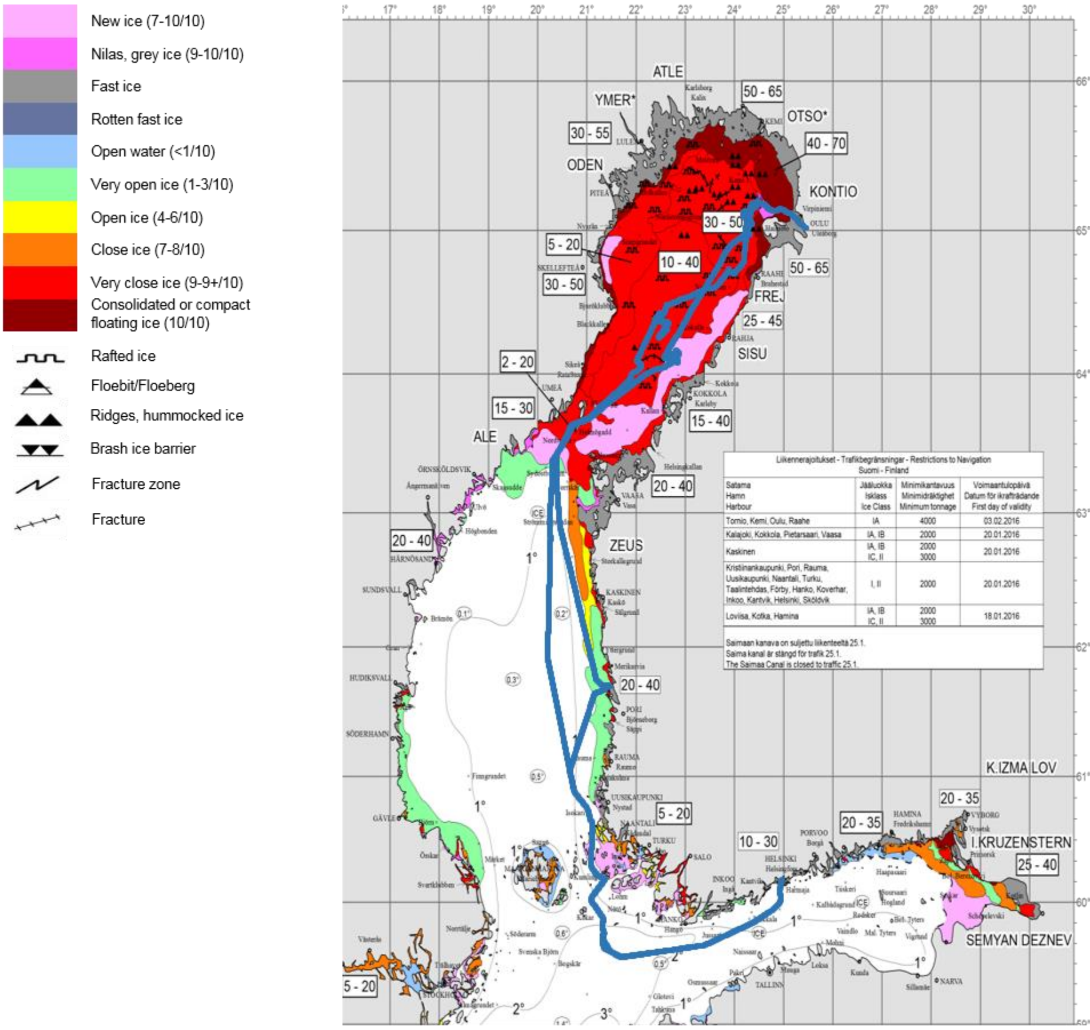

Figure 4. Ship route (the blue line) during the expedition and the general ice condition in the Baltic Sea on March 1, 2016. Ice chart obtained from Finnish Meteorological Institute (FMI).

After a short docking in the harbor, Aranda headed to the Northern part of Bothnian Bay. The following days followed the same pattern, the locations were searched from the drift ice areas from the evening to the morning, and the field measurements were conducted during the daylight time. All together, six ice stations IS1-IS6 were established at locations summarized by Table 1. Due to the mild winter, the level ice thickness was low for the time of the year. However, the ice stations were established in areas of deformed ice, where only little level ice existed (see Figure 4). After IS6, in the afternoon of March 9, the ship headed towards Pori where she arrived in the morning of March 10. The ship then continued towards Helsinki arriving to there in the evening of March 11.

Table 1. Times and locations of the Ice Stations.

Station	Date	Time (UTC)	Latitude	Longitude
IS1	Mar 4, 2016	11:09	65.11° N	24.19° E
IS2	Mar 5, 2016	7:54	65.05° N	24.12° E
IS3	Mar 6, 2016	8:38	65.09° N	24.18° E
IS4	Mar 7, 2016	7:28	64.41° N	23.52° E
IS5	Mar 8, 2016	7:15	64.21° N	22.29° E
IS6	Mar 9, 2016	8:03	63.58° N	22.06° E

RESULTS AND DISCUSSION

Figure 5 presents the results from the drilling measurements of ridge profiles at IS1-IS5. The sonar was employed in three stations, IS4-IS6. Initially we intended to perform sonar measurements at all of the stations, but due to an unfortunate accident, the sonar broke at IS1 and was under reparation at IS2 and 3. At IS1, the width of the ridge was actually greater than presented by Figure 5. These drilling measurements were conducted for validation of the sonar data, and the original plan was to measure the total width with the sonar before it broke. The measurements at IS6 are not reported here, as they included only sonar measurements, accompanied with a few additional drilling measurements for verification. At IS1 and IS2, the drilling included only the measurements on the keel profile. At IS3 – IS5 the measurements included both, the sail and the keel. As shown by Figure 5, the maximum depth of the keel was between three and four meters in all of the stations. The widths of these keels varied from 10 meters up to 25 meters.

The ridges were chosen so that the ship would be able to go through them with a single try. The ship moved to the positive *x*-direction (see Figure 5). This was achieved at IS2, IS4, IS5, and IS6. In IS3, there was thick layer of rafted ice in front of the ridge, which hindered the ship. In this case, the ridge resistance was thus not only dependent on keel thickness, but also due to these rafted layers, which are common for ice ridges (Tuhkuri and Lensu, 1999, 2002). As a result, she was not able to proceed through the actual ridge, but instead had to ram several times in order to get through it. Figure 6 shows a three-dimensional presentation of the ridges at IS3 – IS5. This type of data could be straightforwardly used as an input data for simulations of ice loads involving ice rubble or ridge keels.

Figure 7 shows the comparison between the sonar and drilling measurements, plotted on the top of the gray scale image of the ridge keel. As can be noted, the different measurements show fair correspondence, as was also seen in the similar measurements by Heinonen et al. (2015). The figures have the coordinate system translated so that the bottom of the intact ice sheet aligns with $y = 0$. This is due to the automated processing of the sonar images where the goal was to detect the bottom of the ice sheet and set it to $y = 0$. Hence, having the horizontal dark area aligning with $y = 0$ demonstrates that this type of automated image processing is fairly straightforward to implement with standard tools. Naturally, if the distance from the bottom of the ice sheet to water level is known, the translation back a coordinate system that has the water level at $y = 0$ is trivial. This distance can be always measured from the same borehole that is used for the sonar.

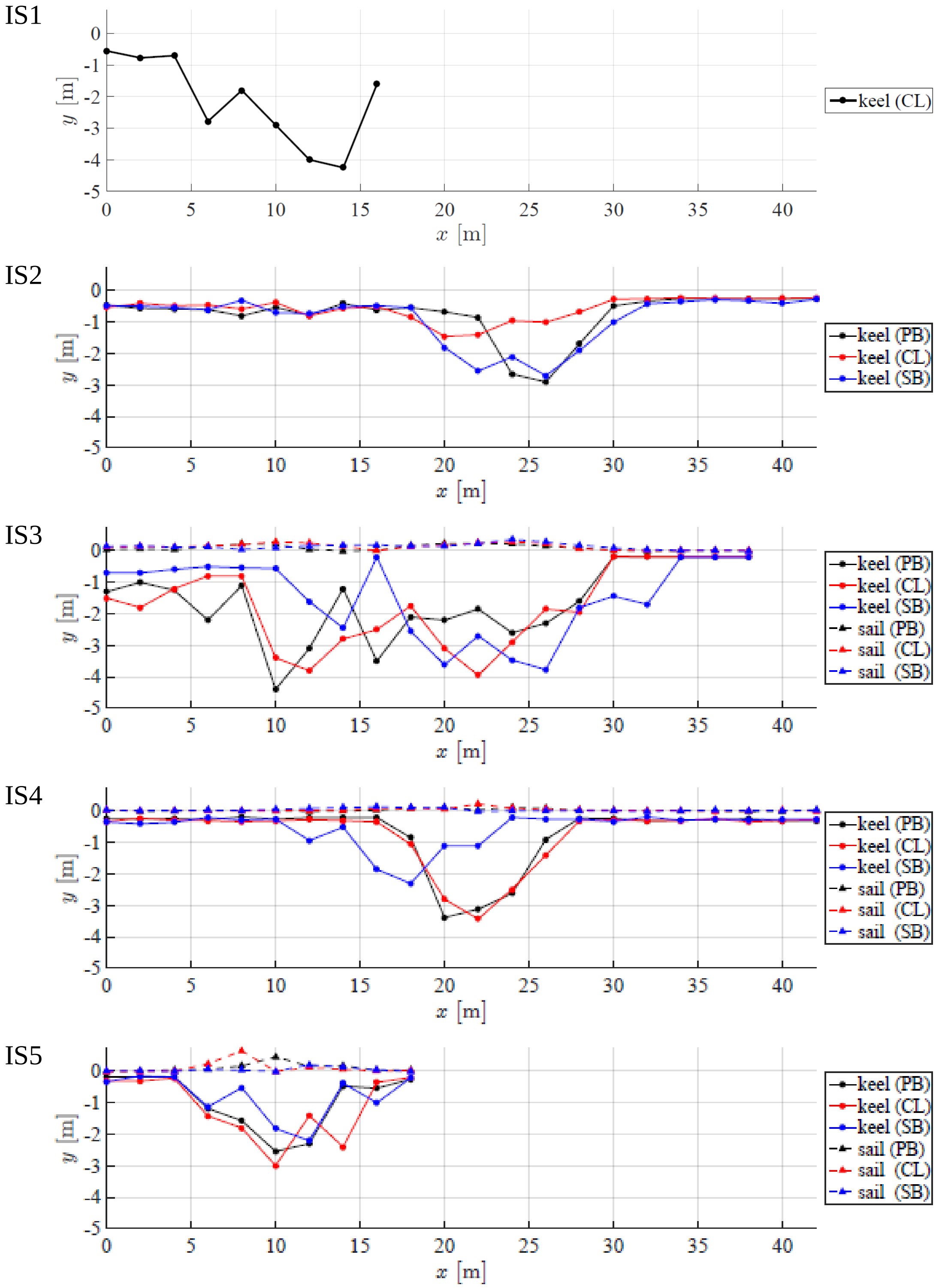

Figure 5. Results of the ridge keel profile measurements done by drilling measurements at ice stations IS1-5. Abbreviations used in the legend: PB = port side, CL = center line, and SB = star board. The horizontal distance between the drilling lines, SB-CL and CL-PB, was approximately 5 meters.

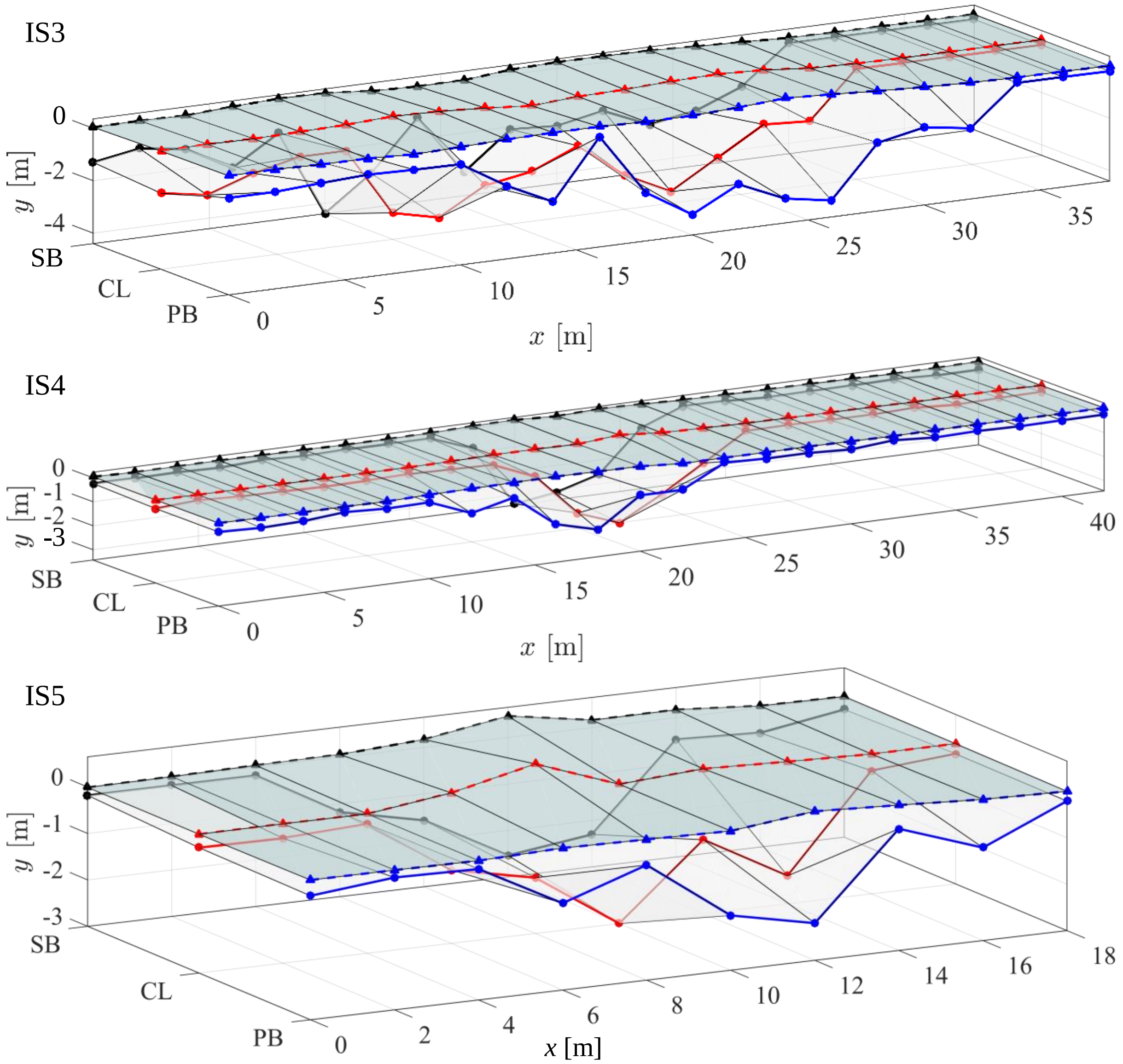

Figure 6. Data from drilling measurements at IS3-5 collected into three corresponding 3D surface plots.

As Figure 7 also illustrates, often it appeared that the sonar data would have given higher keel depth values than the drilling. For the star board (SB) line of keel in the figure, the drilling has likely bypassed an upwards-turned ice block close by. This block could lead to an over estimate of the keel depth (assuming that the drilling gives the ground truth data). We noticed, that in some cases the sonar data was difficult to interpret, and believe, that the properly processed image data, when available, should be used as support of the measurements. This was especially seen from the data from one of our ice stations, which showed that even small interferences in the echoes picked up by the sonar may lead to severe error in the measurements.

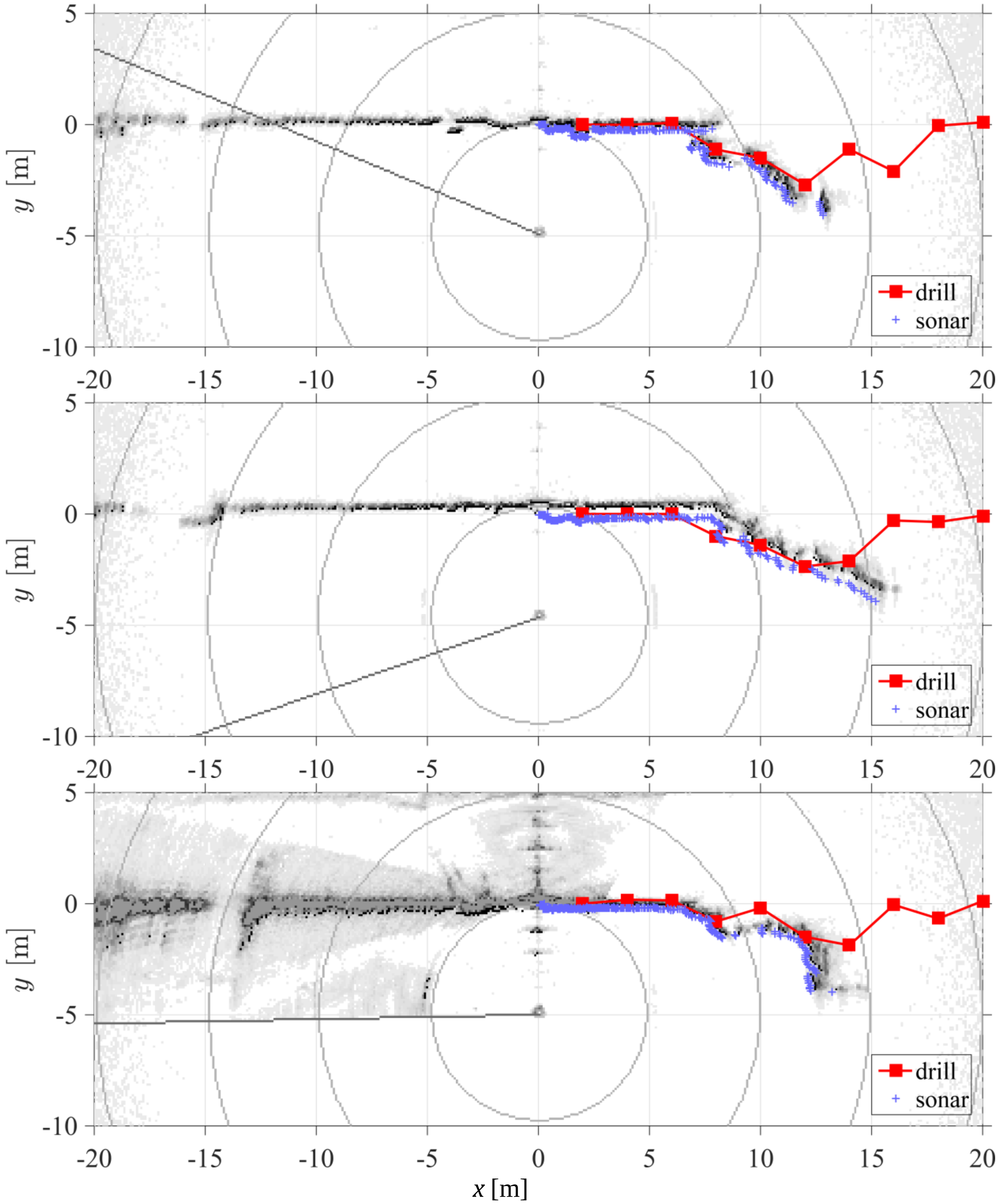

Figure 7. Comparison of the drilling and sonar measurements at IS5 from the centerline (top), port side (middle), and star board (bottom) drilling lines. The '+' markers are the data points given by the sonar software. The data is from the measurements with sonar head frequency 1200 Hz. Here the data is translated so that the bottom of the intact ice sheet aligns with y = 0.

CONCLUSIONS

The paper presented ridge profiles from five different locations in the Gulf of Bothnia determined by drilling. The maximum depth of the ridge keels varied from three to five meters, and the width of the cross sections from 10 to 25 meters. It should be note that ridges were chosen so that the ship would be able to get through them with a single try. Thus, the choosing was subjective and the ridges do not give typical representation for the ridge profiles in the area. The study showed a fairly good correspondence between the drilling and sonar measurements, but also suggests that the sonar image data, if available, should be used as a support when interpreting the sonar data. The remaining data will be processed and studied in the near future. The collected data is to be employed in the model scale measurements in Aalto Ice Tank when ridge resistance is studied in model scale.

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