

## **Sea ice thickness distribution and 1 ice keel characteristics in the Bothnian Bay based on high resolution ADCP measurements**

by Bjørk, G., et al.

### Summary:

The manuscript presents and analyzes a new continuous sea ice draft data series from the Bothnian Bay for the ice season of 2023/2024. The series was acquired by a Nortek Sig500 ADCP set to a mode that enables a parallel measurement of sea ice drift with a 10-minute interval and sea ice draft with a minute resolution. The acquired data span over 700 km of sea ice surface and demonstrates the evolution of sea ice thickness pdf during the winter season of 2023/2024. From the analysis of changes of the sea ice draft pdf the authors demonstrate a crucial role of sea ice dynamics in the area pointing to the dynamic ice production to outweigh the thermodynamic growth especially in the months of March and April. Details on ridge keels statistics are presented. The authors further compare their results with remote sensing data (S-2 surface reflectance) to show a qualitative agreement between the spatial variability in surface reflectance and the measured ice draft gradient. Analysis of available weather data is also conducted to put the 2023/2024 ice conditions in the area in the context of other winter seasons.

In general, the study presents a valuable relatively high-resolution data series useful for scientific and management applications. Despite (and very unfortunate) poor performance of the internal AST and LE -based algorithms for draft determination, the authors successfully used an alternative 1-minute draft data series. With relatively low ice drift speeds in the area, it enabled the authors to achieve a relatively high spatial resolution in the draft series including identification of individual ridge keels. Some more details/discussion/assessment of limitations of the data, especially with respect to detection of ridge keels for periods with higher drift speed and its effect on the derived statistics should however be presented.

There are a few comments that should be addressed; these are related to ice draft calculations, spatial resolution of the derived series and the resulting ridge keels statistics.

- 1) Distance from the instrument to the lower ice surface – this, I assume, is calculated from the echo returns internally by Sig500 based on water temperature and salinity, right? Or are water temperature and water salinity set as defaults in the firmware of the instrument? Please clarify this question.
- 2) Temporal variability in S and T in water column above the ADCP will introduce some time varying bias in the retrieved ranges ( $D$ ) through variations in the column-average speed of sound. Did the authors assess the significance of possible effects of these variations locally?
- 3) A follow up of comment (2). In Eq. 3 the authors introduced the correction factor  $\delta$  which the authors postulate to be constant. This correction factor can actually accommodate the bias due to changing speed of sound. How many open water events have you used to prove this statement? Are the open water events evenly distributed

throughout the winter period? Good to show the plot of  $\delta$  throughout the winter season in, e.g. Supplementary materials. It well indeed can be constant if the water column is well mixed and S and T measurements made by ADCP (if this is the case) are representative. Please comment on this.

- 4) The authors postulate that a 1-minute draft series is sufficient to reconstruct a bottom topography with a resolution sufficient for isolation of individual ridge keels. This is indeed correct for a certain fraction of ice drift conditions (Fig.21) when drift speed was low enough. Apparently in case of high drift speeds detection of keels may not be possible. For the intermediate drift speeds like 0.1 m/sec (6 m sampling increment), keels below 18 m wide could not be resolved. In such conditions any means will always be biased high unless some speed thresholds are applied for making statistics. Was it considered in Table 2 where ice keel statistics is presented? Was any resolution cutoff applied for ridge keel detection? Good also if Table 2 can be supplemented with a fraction of time/month and eventually ice distance when ridge detection was possible/not possible. This can give a hint on the true number of ridges that could have travelled over the mooring.
- 5) The paper can be shortened without a loss of context. Now it includes 21 figures: some can be combined, others moved to Supplementary materials. I made some suggestions in the other comments listed below but I do recommend the authors to think through the concept of the paper and retain the most important details in the main text leaving the rest for Supplementary.

Minor to moderate comments.

Page 3-4. Can one consider combining Figures 1 and 2?

Page 4: "...the Nortek software sought a maximum in echo intensity elsewhere in the water column. There are also unrealistic data when the LE distance changes with the same increment between data points for a series of points, which appears as lines with constant upward slope and located well below the expected ice surface."

I assume here the authors present two types of anomalous data. The first is caused by reflections from various objects other than the sought bottom ice surface, like bubbles, troughs of surface waves (in case of open water conditions), or different objects of biological origin etc. The second sounds like a description of multiple reflections (or double bounces) when the instrument logs the echo of a second (or even third) return.

Page 4: "However, the AST data has a minimum distance of about 13.5 m which makes this method not useful for drafts larger than about 7.5 m." what was the rationale behind this threshold?

Page 5: "An estimate of the total ice thickness can easily be found by multiplying the draft with some isostatic factor of around 1.14 obtained from literature (e.g. Vinje et al., 1998)." Note that this factor was based on measurements made on summer sea ice in the 1980s in Fram Strait (i.e. on preferentially older ice types), with reduced snow load or even without snow at all. So, good

to mention that the actual ice thickness would vary depending on ice density variations and snow load.

Page 10: “The ice was mobile during the first month of the period such that the ice speed followed the wind speed rather closely which indicates that the ice cover was mostly in free drift with low internal stress. Later, in February and March there were numerous occasions when the ice was standing still despite significant wind speed.» What was the effect of storm Ingunn in late January the authors have mentioned on sea ice drift?

Page 12: “The detail (Fig. 8c) shows that the ridge structures appear to be well resolved by the 60 s sampling interval.” Please see my major comment (4). Note also that the example demonstrated in 8c is for the period when the drift speed was below 0.1 m/sec, i.e. leading to ca. 6 m spatial resolution and implying ridge structures less than 18 m wide could not be resolved with such sampling rate. Should be mentioned.

Page 16: “Most of the keels had a width of 6-40 m resulting in typical aspects ratios of 5.5-6.5.” The same comment as before. Keels of the width as low as 6 m could be detected only in conditions of almost no drift (with a 2 m spatial resolution required by a drift speed of 0.05 m/sec ). Makes sense at least to emphasize, that “most of the *detected (or isolated)* keels...”

Page 16: “The number of observed rubble-like structures (width more than 100 m) as well as the maximum width is presented in Table 2.” This statement needs to be considered in the context of the spatial resolution, as such “rubble fields” when detected during fast drift periods can also be unresolved keels. It is known that ridges are not evenly distributed along the ice surface but rather tend to cluster in space.

Page 19: Figure 16. I wonder if there were any tidal effects registered in ice drift pattern?

Page 17: Figure 17 – cross is very difficult to discern.

Page 21: Figure 18 can be placed into Supplementary

Page 21: “...assessment, exploring whether high-resolution optical imagery can detect 496 ridge sails as manifestations of subsurface keels. Based on the present dataset, the sensitivity appears limited. Radar-based approaches, such as SAR, which are more responsive to surface roughness and independent of illumination conditions, may provide a more suitable framework for future work.” This can be moved to Discussion

Pages 21 and 22. Figures 19 and 20 can be moved to Supplementary (or at least combined into a single two-panel figure)

Page 22: “is not seen at all in the EM data having near zero frequency already at 4 m ice thickness and where the thickness bins end at 5 m.” Heli EM is known to undercount deeper ridges due to a large footprint of the EM-bird (about 50 m as far as I remember). Detailed comparison is therefore not straightforward if not impossible at all.

