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The Cryosphere
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Interactive comment on "Estimation of degree of sea ice ridging in the Bay of Bothnia based on geolocated photon heights from ICESat-2" *by* Renée Mie Fredensborg Hansen et al.

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Please find our comments to each section/subsection in the RC1. The reviewers comments are provided first, and then authors response, separated by '—'.

— 1. General comments

— 1.1 Paper Synopsis

I found this to be an interesting paper on a topic of significant human relevance. In it, the authors use the ICESat-2 laser altimeter to retrieve the ridginess of ice in a way comparable to that traditionally charted by ice analysts for marine navigators. I believe their

analysis to be generally rigorous, and the figures in particular were well presented. I have relatively few concerns about subsequent publication of this manuscript, although I would like my questions concerning ridge-alignment anisotropy and cloud-cover to be directly addressed before publication.

— Authors response:

We would like to thank the reviewer for the positive and insightful comments. Please find below our initial response to the comments.

— 1.2 Reproducibility

It is unfortunate that the FIS charts are not publicly available, and so this analysis is not replicable without contacting the authors. I do however appreciate that this is not within the authors' control if FIS insist on holding the copyright. It was pleasing to see the analysis code uploaded to an open repository, with nice use of markdown for context. Although this is beyond the remit of my role as reviewer, I would encourage the authors to ensure that all defined functions have docstrings so as to boost code readability. I would also encourage the authors to consider storing their code in a persistent location such as that provided by Zenodo, for which it will receive a digital object identifier (DOI).

— Authors response:

It is a very good thing the reviewer pointed this out. The Finnish Meteorological Institute has an open data policy, and by definition products like FIS ice charts should be publicly available. The sea ice concentration and thickness from the ice charts indeed is available through the Copernicus Marine Environment Monitoring Services (product SEAICE_BAL_SEAICE_L4_NRT_OBSERVATIONS_011_004). However, the Degree of Ridging is not included yet. Thus we have started the internal process at FMI to make them available, and the response from FIS has been very positive. We hope that the DIR will be publicly available as SIGRID3 and NetCDF files at the time we shall revise the manuscript.

We will ensure that all defined functions have docstrings to boost code readability and will also store the code in a persistent location, for it to receive a DOI. This will be achieved by the time we revise the manuscript.

— 2 Specific comments

— 2.1 L126: “We also discarded all measurements that deviated from the geoid elevation by more than 3 m”. I feel like the reader would benefit from knowing what fraction of photons this is? Is there a risk that you’re throwing out more photons during high tides than low tides? What’s the typical sea surface anomaly on the geoid here? Wouldn’t you be better off discarding measurements based on their deviation from the tide-corrected sea surface?

— Authors response:

We will add the fraction information in the revised manuscript.

We appreciate the reviewers comment on this, but will highlight that in the Baltic Sea (and in particular in the Bay of Bothnia), the effect of tides is negligent. Overall, in the Baltic, the maximum tide measured by tide gauges has ranged between 18-23 cm (Medvedev et al., 2013, 2016), but within areas not part of the south-western Baltic, tidal amplitude observations have not exceeded 10 cm (Lilover, 2012).

— 2.2 Fig 2: what are the units of the y axis? I appreciate that because it’s a histogram, ‘Density’ corresponds to the number of relevant photons per bin, but what’s the bin-width? Without knowing that, the specific values on the y axis are meaningless. Just an idea, but consider displaying this data as a probability density function (i.e. plot the probability of the max-height photon having a given elevation anomaly). By doing that you could perhaps squeeze in some meaningful information on the y axis rather than it just being ‘density’.

— Authors response:

We will look into if other plots (incl. the one mentioned by the reviewer) might provide

additional information beyond the density plot already included.

— 2.3 L211: You talk about the drift pattern in the Bay of Bothnia being West to East. I imagine a consistent drift-pattern like this would produce an anisotropy in ridge orientation (probably aligning them along the North-South axis?). Because IS2 tracks also run broadly North-South, it seems to me you might have a sampling issue here, particularly with regard to ridge density. To restate this, you’re only measuring ridge-density along one direction, and that’s (generally) the direction that the ridges themselves might preferentially run. I feel this needs to be addressed in your discussion. Are ridges aligned anistropically in your study area? Can you use the fact that IS2 has non-parallel ascending and descending tracks to get a handle on this?

— Authors response:

Excellent point. The preferred orientation of ridges has indeed been overlooked in our manuscript! We could, unfortunately, find no peer reviewed literature on the ridge orientation in the Baltic so we asked for help from the FIS. They produced an old study on ridges in our study area, and it is apparent that the ridges tend to form parallel to the fast ice edge - which in turn is parallel to the coastline. See the image below, showing the ridges in Bay of Bothnia during winter 2013-2014. The anisotropy will have an effect in the ridge density, which we shall discuss in the revised manuscript. However, as the reviewer points out, this is likely mitigated by the orbit pattern of ICESat-2. Furthermore, by no means all of the ridges are oriented in the same direction, but especially in areas of heavy ridging the orientation distribution is even (see Fig 1).

In the spirit of discussion, we would also like to point out that ICESat-2 ridge detection might open possibilities to study the ridge orientation in remote seas. Quite possibly one could see preferential orientation in areas such as the Kara Sea by comparing statistical ridge densities retrieved from ascending and descending orbits! But this, for now, is beyond the scope of the paper at hand.

— 2.4 This paper argues that IS2 DIR retrieval would be of significant operational benefit to ice analysts, but does not substantially address the impact of cloud cover on measurement availability (although it does discuss the role of low lying clouds on surface ranging biases). The authors state that only 25 granules of data were available in the three-month period that they searched within. Firstly, I feel that a reader that is non-expert in IS2 would benefit from the term ‘granule’ being defined here. Second, while this number is of some use, I think the reader would benefit more from knowing on what number of days can the study-area be analysed for DIR in this way? Were those 25 granules confined to a small cluster of days, or do the granules represent the three month time period well? Are there some months where DIR is more retrievable than others due to cloud masking? These questions significantly affect the utility of the proposed retrieval method.

— Authors response:

We will address this in the revised manuscript. During the period of January 2019 - May 14th 2019 (when the ice season ended), a total of 41 granules intersected the Bay of Bothnia, but only 25 were (by visual inspection) considered either partially-impacted by clouds or cloud-free. Of these 25 granules, we found that only four traversed a ridged area during the mild winter of 2019, which happened in February (beginning of the deformation, less ridged areas) and in March (high deformation, heavily ridged areas occur here). In April-May, all granules were completely impacted due to the cloud-cover. However, this was not the case in January-March, where granules also were not clustered, but were evenly distributed throughout the months, thus they represent the three-month time period. Hence, we want to emphasize that although there were a high number of useful granules (25), only 4 intersected a DIR area (DIR2-DIR4) within the reference data set that could be used in this study.

— 3 Technical points

— Authors response:

All technical points will be taken into account when revising the manuscript.

— References:

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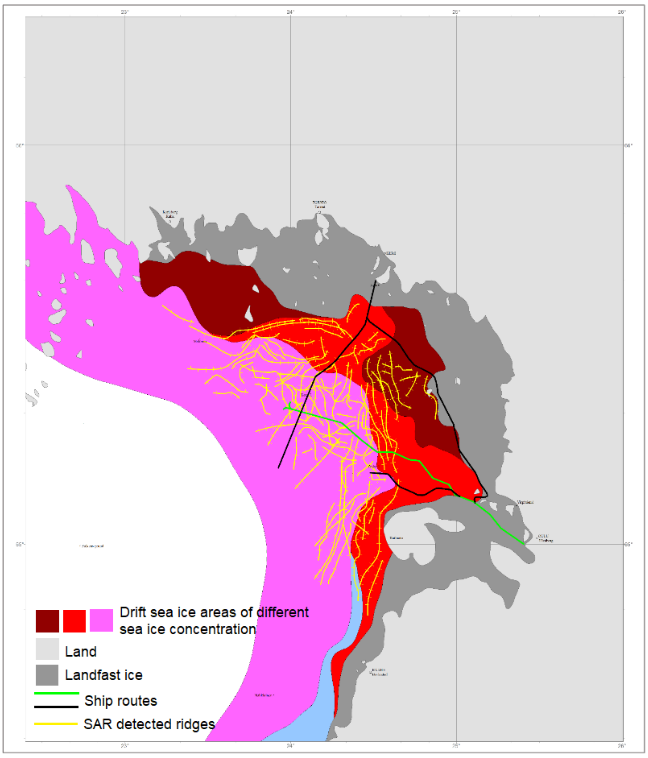

Fig. 1. Ridges close to the ports of Oulu and Kemi, winter 2013-2014. Courtesy of FIS/Finnish Transport Infrastructure Agency.