

The Cryosphere Discuss., author comment AC2
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Reply on RC2

Mikko Johannes Lensu and Markku Henrik Similä

Author comment on "Ice ridge density signatures in high resolution SAR images" by Mikko Johannes Lensu and Markku Henrik Similä, The Cryosphere Discuss.,
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Overview

The work presents a new method to derive sea ice ridge height through bright pixels and ridge sail number in one high resolution and one medium resolution TerraSAR-X image. The paper uses a statistically derived method to connect the SAR images to the ridge density.

We find this characterisation correct.

Major comment:

The text would benefit from being shortened, it's presently very long, 30 pages excl. references, and it deters from making the work shine. The text is in places composed of short sentences making it a bit difficult to read, and some of these sentences are not grammatically correct. This unfortunately lowers the quality of an otherwise nice manuscript build on solid physics. It would therefore be nice to see the work going through a thorough language check.

Both reviewers remark on the length and too short sentences. We clearly should and seek to improve in both matters and will also have the final version of manuscript checked for language. This answer is the same for both reviewers.

It is stated that the work can be used to aid safe navigation, but it could perhaps be explained a bit more thorough how that is planned.

In the example figures we delineate the 30% of most deformed ice as divided into three 10% classes. Although the conversion factor to actual rubble coverage is lacking and the height characteristics is not known a ship entering the area may provide these by its own observations and then distinguish easily navigable areas from those it should avoid. The spatial distribution of the classes can be also complement ice charts that estimate the total deformation form different sources. A third possibility, possible in the frequently navigated Baltic, is to determine from AIS data the ship response to the classes and use this to interpret them in terms of difficulty of navigation. We will add some sentences in this theme.

This study is conducted using X-band images, which possibly due to the high resolution offered by TerraSAR-X, is renowned for being very good for ridge detection. Would it be possible to transfer this study to the operational used C-band SAR images? Perhaps the authors could speculate if this would be possible and what implications it would have. As the study is done by authors at FMI is it perhaps possible to also find overlapping C-band images for the time and area of the X-band images used in this study?

As we commented also to the other reviewer we expect the method to apply to other bands if the brightest returns are predominantly from ridge rubble. We sought to support this by operations that obscured the ridging signature in the image but not in the contextual image. Conditions where the wavelength matters can be conceived however, as remarked to the other reviewer.

*By inspecting the results shown in Mäkynen (2004) for the scatterometer data at X- and C-band, we notice that the discriminative power of **sigma0** between different ridging categories is roughly the same at X- and C-band. This applies also to the difference between level and ridged ice areas. This study suggests that the proposed method works also for C-band SAR imagery. Further studies are expected to clarify these issues, and IceSAT-2 can provide a source of validation data.*

The air temperatures were quite high during the time of the SAR image acquisitions, up to -1C. How will this affect the analysis? As ridges often trap more snow than the level sea ice, would the method presented here be more sensitive to a temperature change than a level sea ice area.

Shortly yes. The temperature controls the amount of wetness in the snow cover. With increasing snow depth and/or snow wetness the backscattering decreases. Due to aeolian transfer the snow tends to accumulate in ridge sails. If average snow thickness is small smooth level ice areas may even be snow free and all snow is accumulated against sail slopes. Our earlier results (Haapala et al. 2013) indicate that for thick snow cover (average ~0.45 m) the snow thickness in ridge sail rubble areas may be almost twice the average and snow can cover completely individual sails with height up to three times snow thickness. Thus if the snow is moist the effect is significant. The upper parts of higher sails usually remain ice free in windy conditions however. Thus the contrast between ridges and level ice may decrease on the average but bright returns from upper sail parts are expected to remain. For an extended area with homogenous snow and sail height conditions the density of bright returns is then intergral sum over the returns from sail height classes for which the returns are conditioned by snow thickness. However, for each class the returns can be assumed to follow the same randomness that obtains for snow free conditions, and the hypothesis behind the statistical model can be assumed to still hold. Hence the method is sensitive to temperature and snow thickness but is nevertheless able to detect variations in ridge rubble coverage. The conclusion is that our basic hypothesis that the brightest returns come from ridge rubble remain valid in most cases except possibly in very wet and thick snow conditions over shallow ridges when the contrast between level and ridged ice disappears and the backscattering level overall is low.

We will seek to communicate, without extending the text too much, the essential content of the above argument on the effect of snow, temperature and other ambient conditions. In short, the generative hypothesis behind the statistics is that a small increase in bright pixel percentage changes the bright pixel numbers in way that depends linearly on BPN; and there are reasons to expect that changes in ambient conditions follow the same pattern and therefore do not change the statistical model but only its parameters.

(Haapala, J., Lensu, M., Dumont, M., Renner, A.H., Granskog, M.A. and Gerland, S., 2013. Small-scale horizontal variability of snow, sea-ice thickness and freeboard in the first-year

ice region north of Svalbard. Annals of Glaciology, 54(62), pp.261-266.)

HEM thickness measurements tend to underestimate thick and deformed ice (see, e.g., Haas et al., 2009; Mahoney et al., 2015), how will this affect the results presented here? What is the resolution for the laser data?

HEM data may be used to construct that are used to convert surface elevation characteristics to thickness characteristics. Due to the footprint (a few meters) HEM blunts the maximum keel depths and the porous ridge keel may have nonzero conductivity that results to underestimation of average thickness if not accounted for in the HEM inversion model. On the other hand, HEM instruments are usually able to penetrate through thickest Baltic ice types. In any case, the conversion of surface characteristics to thickness is not among the topics addressed in the paper and is rather an independent problem shared by all approaches to thickness using surface data only. The laser measurement interval is about 0.5 m.

Minor comments:

It is fair to say that the ground truth data from 2011 was used for both datasets. Perhaps this could be rephrased slightly as it may come across as using 5-year-old data as in-situ could unfortunately question the study in the abstract.

We will rephrase ‘...acquired in 2016 and 2011, and ice surface profiles measured by a 2011 Baltic campaign. The images...’ The use of the surface data in the context of the two images is described later in the abstract, but we add ‘2016’ or ‘high resolution’ and ‘2011’ to make clear that the statistical model is formulated for RSN data that is not concurrent with the high resolution BPN data.

P4R20. Please provide reference/s for this. - *We will refer here to Gegiuc et al., 2018 listed in the same section*

P6R32. “...is used a” -> “a” and move “is used” to later in the sentence. - *Corrected*

P7R20. Is 1/km km⁻¹. - *Yes, 1/km is commonly used in the Baltic context for ridge density*

P8R4. There is a reference to annual maximum extent, could this perhaps also be indicated in Figure 1, also as it is referred to this figure in the end of the sentence. - *This is possible, alternatively we provide both extents in km² as only part of the Baltic is visible.*

P8R13. Where is this temperature sensor located? - *We will add that the drifting station was RV Aranda and that the data is from its weather station.*

P8R26. How were these observations derived? From FMI ice charts? Ice observations? - *FMI ice chart values based on observations and measurements by icebreakers and coastal stations.*

Figure 4 is referred to before Figure 3. - *Corrected*

P17R16. Equation number is missing. - *Corrected*

P23R18. Could the rubble field also be referred to as brash ice?

No, these are different. In rubble field the ice ridges sails are arranged so close to each other that the level ice fraction is minimal or nonexistent. It is a continuous field of ridge blocks, while brash is floating melange of ice pieces of different sizes. Consolidated brash

has rough surface with bright but rather uniform SAR return in contrast to the randomly scattered bright returns from rubble fields.

P25R9 (?) *Corrected*

P28R12-16. How were the scaling factor derived? Was there a statistically based fitting?

The scaling factor is from the slope of the quantile plot. The HEM RSN data followed gamma distribution in the continuous limit. Ridge density is special case of RSN statics for 1 km segment length. The HEM RRC of eq (6) inherits the gamma as it depends linearly on the ridge density. The SAR RRC is then also gamma as the quantile plot is linear. So we did not make statistical fitting here but the the statistics is derived from the validation of the full scale system (1-3) for RSN in Sec 6.4. We try to make this chain more explicit.

P29R8. Which frequency would be suitable for ridge detection?

According to the literature the L-band is best suited for ridge detection, see e.g. Dierking (2010)

*(Dierking, W. Mapping of Different Sea Ice Regimes Using Images From Sentinel-1 and ALOS Synthetic Aperture Radar, IEEE T. Geosci. Remot S., 48(3):1045 – 1058
<https://doi.org/10.1109/TGRS.2009.2031806>, 2010)*