

The Cryosphere Discuss., author comment AC1
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Reply on RC1

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

This manuscript presented an approach to studying sea ice ridges from medium- and high-resolution SAR imagery from TerraSAR-X validated against Helicopter-born EM (HEM) datasets acquired over the Baltic sea. This study proposed a method to delineate linear ridge features from SAR images regarding the local density of bright SAR pixels over a certain percentage. This study found a linear relationship between SAR bright pixel percentage (BPP) and HEM ridge coverage. Although acknowledged, this study does not contribute towards quantifying sea ice roughness/ridges corresponding to SAR backscatter, which is a major gap in the sea ice literature. However, this study argues that the proposed method can aid safe navigation through ice-infested water.

We find this characterisation mostly correct. On the question of quantifying ridging from SAR we remark that the approach can describe the variation of ridge rubble coverage in a relative fashion. Local measurements of ridging conditions, IceSAT-2 profiles, or observations from an ice going ship can be used to locally remove or reduce the relative uncertainty and the result can be extrapolated to an extended area. The other aspect of ridging quantification from SAR, or ridge height, remains a gap as remarked. However, ridge sail block dimensions increase and the sail geometry scales up on the average with ridge size as larger ridges are created from thicker ice. If the bright returns are from favorable block arrangements the distances between neighboring bright returns should then increase with ridge size. We did not follow this clue further as we did not have matching surface data for the high resolution image.

Major comments:

The paper provides important details on the subject matter, works of literature, and proposed methodology, supported by necessary figures. My major comments are as follows:

I have a concern regarding the structure of the paper. The paper is comprehensive; however, sections 1-3 can be synthesized well to shorten the length. There are a few very short sentences in the manuscript, which can be added to the previous sentence. Similarly, a few very short paragraphs can be merged with the previous section to keep

the flow consistent in the manuscript. Please check and correct this issue throughout the manuscript. At least, section 2 needs to be synthesized to have a better flow of the content, which I find scattered in the current version.

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.

The methods and results are mixed in sections 4-7, making it difficult to follow. I think the authors should separate results and discussion.

We considered this carefully when writing the paper and also had an earlier version with methods and results more clearly separated. This made the methods section long and difficult to follow as the statistical model, which is expected to be novel for most readers, must be expounded and validated both for SAR and for the ridge data. This was further complicated by the fact that the ridge data set is compared with non-concurrent high resolution image in terms of the statistical model while for the medium resolution image the ridge data is concurrent validation data. We considered also the possibility to present the theoretical parts as an appendix. These parts contain however the main new methodological advances towards the quantification of ridging from SAR and should in our opinion be presented in the actual paper. There are also several different and in part independent methodologies introduced in the paper. Thus we found the present arrangement, where each methodology is followed by results, a more accessible alternative.

In Section 5 we present the approach of counting BPN in pixel blocks with some practically oriented methods of presentation. This section ends to an introduction to main statistical idea, or the considering how BPN values change in small changes of BPP. This section might better serve as an introduction in Section 6 when combined with introductory parts of 6.1. We will also try to make more clear in Section 6 what is the basic approach, what are theoretical validations of the concepts, and what are the applicable results. The simulation exercise in 6.6. was intended to provide additional validation to the basic concepts but it also illustrates these in an easily understood way. We find ourselves the result quite striking but presenting it earlier in the paper might raise confusion on what is the subject matter. Section 7 is a detailed application/validation study that uses only the primitive concepts of the approach to compare SAR and surface data but seeks to be careful in its use of validation data.

When TSX was acquired, the paper motioned the air temperature as -2.3 degrees C. Since the ice was first-year sea ice and the snow had brine, I wondered whether the snow was brine-wetted at the bottom had an impact on X-band backscatter. A sea ice study on C-band SAR imagery reported moist snow at -3.1 +/- 1.5 degrees to have a melt onset signature. Since air temperature was warmer in Baltic during TSX acquisition, how could this affect the SAR statistics presented here?

The water salinity in the Bay of Bothnia is from 3 to 4 permille. Ice bulk salinity typically less than 1 permille for level ice and ridge blocks can be almost fresh; we add the following reference (A.J., Weeks, W.F., Kosloff, P. and Carsey, S., 1992. Petrographic and salinity characteristics of brackish water ice in the Bay of Bothnia. CRREL Report 92-13).). The field measurements of ice samples reported by Hallikainen (1992) (will be added as reference) had ice salinity range from 0.2 to 2 permille depending on the location, time, and weather history.

Brine expulsion on the surface may occur for thin level ice after rapid freezing but is expected to have drained from thick midwinter ice in the Bay of Bothnia that also does not become flooded by snow load any more. Thus we do not expect that any consequential

flooding occurred in the SAR covered areas. In the case of the flooding the salinity of brine is low and brine would effect on the backscattering level mainly through the increasing snow wetness. So the role of salinity is small. Some moisture in the snow cover in the 2011 TSX data probably have slightly decreased the contrast between level and ridged ice. However, a large fraction of the ridges are still visible as seen in Fig.13. The assumption that the bright returns are predominantly from favorable ridge block arrangements is valid in these sea ice conditions.

We can address this in the discussion section.

Minor comments:

Since the manuscript focuses on TSX images, the title should reflect the frequency used in this study. Please include 'X-band' in the title.

The methods are not restricted to X-band and we believe that the results would have been similar if the SAR images available to us would have had different band(s), that is, the assumption that brightest returns are predominantly from ridges would have been valid. The soundness of this generally known property has been demonstrated for the X-, C- and L-band in the Baltic Sea, e.g., in studies Mäkynen (2004) and Dierking (2010). There are some sea ice conditions outside ridging which generate strong radar response, brash ice zones likely being the most common. Hence the identification of open water and brash ice areas must be done before the application of the proposed method. However, the functionality of the method needs to be systematically studied and conditions where the assumption does not hold can be conceived. We will address this in the discussion section and would like to retain the title as it is.

If section 7.1 can be considered validation, the title should show that information so that the reader can refer to the section title to find necessary information without going into the details of the text. discriminative

We work towards improvement here, e.g. in terms of subsections.

Was both the imagery acquired in ascending or descending mode? Please confirm. A mixture of modes can seriously impact SAR backscatter from ridge sail direction.

In our case the time interval between the fine and the medium resolution images is five years and the target area for the images is hence not the same. We believe that even if the time difference would have been short and imaging from different directions would have applied, the proposed method should have yielded similar statistics. The method refers the statistics of ensembles of pixels (pixel blocks), not single pixels. For each pixel in the block that contains ridge rubble it depends on the favorable arrangement of the ice blocks whether the pixel has a bright return (i.e. one above the assigned intensity threshold) or not. As the orientation of ice blocks is basically random the same applies to the occurrence of favorable arrangement and bright return. If the modes or angles are different, different pixels in the pixel block will appear bright and also the number of bright pixels is likely to change. Due to randomness the same statistics is expected to emerge.

However, we would like to remark on possible effect of the incidence angle in each SAR image (e.g. Mäkynen and Karvonen 2017) . This may affect also the statistics although ridge sails as sloped features of randomly oriented scatterers are less sensitive to incidence angle effects. In the high-resolution image used to study the BPN statistics no effects could be discerned and the change of incidence angle across the 8.7 km wide study area may be neglected. For the medium resolution image study area extending about 60 km laterally this situation may be different but is obscured by the gradient of the ridge density towards the Finnish coast. We will address this issue in the discussion.

(Mäkynen, Marko, and Juha Karvonen. "Incidence angle dependence of first-year sea ice backscattering coefficient in Sentinel-1 SAR imagery over the Kara Sea." IEEE Transactions on Geoscience and Remote Sensing 55, no. 11 (2017): 6170-6181)

We also corrected the issues in the remaining comments below:

In-text references are not included correctly. For example, page line 17 should be 'As verified by Dierking (1999)...'. Please correct similar issues throughout the manuscript.

Page 17, line 16

?? should be replaced with an equation number.

Page 25 line 9

What does '?' denote?

Page 26 line 1

Check and correct the section title

Page 23

Section number needs to be updated after 7.1. Currently, the result section shows 7.1.1. One section in between does not have a section number.