Response to referee 1: Estimation of Degree of Sea Ice Ridging Based on Dual-Polarized C-band SAR Data by Alexandru Gegiuc et al.

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This is a good paper. The importance of navigation charts in ice infested seas is undeniable and ridging ice is an important parameter for navigation. The paper would benefit from a good proof reading.
We thank the reviewer for the appreciation given to the topic discussed here. We have carefully improved the readability of the paper.

I put comments below that I consider should need attention:
P1. Line 17: change se thickness to ice thickness
Done.

P1line 21 and 23: change Seina and Peltola (1991). to (Seina and Peltola, 1991). All text: references are wrongly cited (might be LaTex-based problem)
Corrected.

P2. L18 I wouldnt say that these egg code polygon represent uniform ice areas but uniform areas with up to 3 ice types (normally)
In the daily ice charts provided by the Finnish Ice Service is not used the egg code for the polygons. The sentence is corrected to:
"The ice chart polygons defined by the ice analysts represent ice areas with similar ice characteristics."

P3. L26-34 I think this could be simplified to half of that.
In the context of the discussed topic of sea ice ridging and its importance for navigation, we consider that the proposed (full length) paragraph describing the Baltic Sea ice conditions for the selected data set is relevant and needed for a better understanding and interpretation of the obtained classification results. Therefore we propose to keep the paragraph unshortened.

P4. L 8 100 m (use $\sim$ between 100 and m)
Done.

P4. L 23 delete "already"
Done.

P5 L 5 delete "some"
Done.

P5 L 11 correct "CarlstrÅlöm"
Done.

P5 L 16 using ∼ between 100 and m will prevent its separation
Corrected.

P5 L 18 use N 61° 40'
Done.

P6 L 9-16 you should offer some evidence of this problem, otherwise it seems a bit arbitrary.
We agree and we have added a figure (also below as Fig. 1) with an example of an accepted and rejected SAR - chart pair in the data selection process, in the Section 2.4 (in the previous version 2.3).

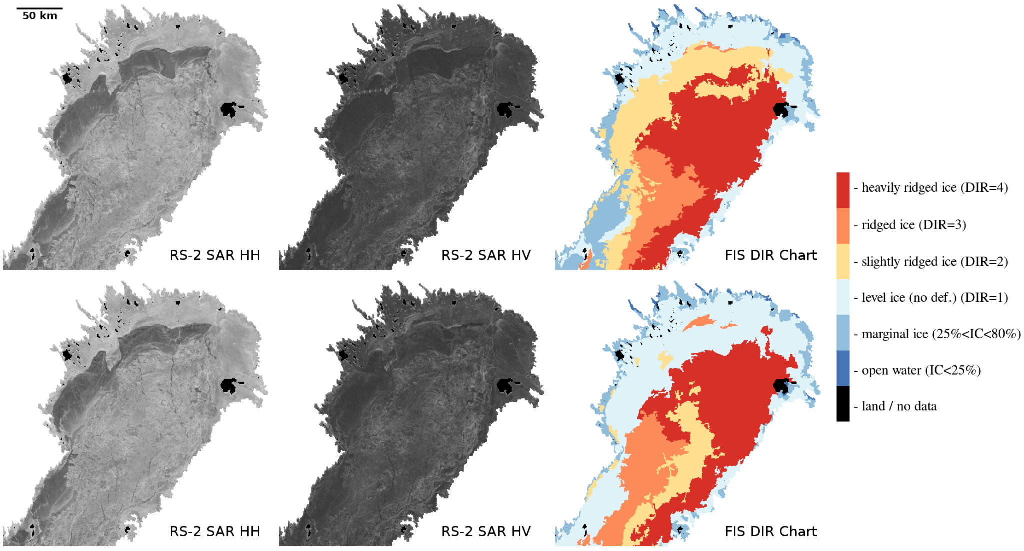

Figure 1: Example of RS-2 SAR data mosaic in HH (left) and HV (middle) polarizations and the corresponding degree of ice ridging chart (right) with values extracted from the digitized Finnish ice charts, for 9th March 2013 in the upper panel and 12th March in the lower panel. In both days the SAR shows similar ice situation, albeit the two DIR charts show changes in the ridging classes: in the NW of Bay of Bothnia, from slightly deformed ice (DIR=2) to level-ice (DIR=1) and in the central to southern part of Bay of Bothnia, from heavily ridged ice (DIR=4) to slightly ridged ice (DIR=2). In this case, the data from 9th March 2013 was removed from the classification.

The example is discussed in detail in the Section 2.4 (in the previous version 2.3).

P7 L 11 eq. 1 should be in multiple lines... very confusing this way
Done.

P12 L 4-7 This information would be better presented in a table.
We have replaced the figure with a table (see Table 1).

Table 1: The importance of different features when the training data covered the whole test period.

feature	FIS SIC	K_{HH}	σ^0_{HH}	ED_{HH}	AC_{HH}	E_{HH}	CV_{HH}	σ^0_{HV}
importance (%)	13.9	11.9	11.7	11.3	8.1	7.2	7.2	6.9

P12 L 11 In summary we found that the RF classification presents the following advantages:
We have added the following paragraph at the end of the Section 3.3.2 which summarizes advantages and disadvantages for the RF classifier in the DIR estimation.
"In summary we found that the RF classification presents the following advantages : i) RF has the ability to describe complex, nonlinear statistical relationships among variables, ii) RF reduces the uncertainty of the obtained estimate, iii) RF reduces the possibility of over fitting. The greatest weakness in RF is its relatively weak extrapolation property (Hastie et. al., 2011). This property can be seen from the behavior of the error rates. The RF classifier has a very low training error rate but the error rates increases significantly for the test set."

P12 section 4.1 it would greatly add value if we could see some of the field data campaign
Based on the Reviewer's recommendation, we have added a figure (see Fig. 2) with the sea ice field campaign data into the Section 2.3 (in the previous version 2.1) entitled now "Surface and thickness profile data on ridged ice", where this data is discussed.

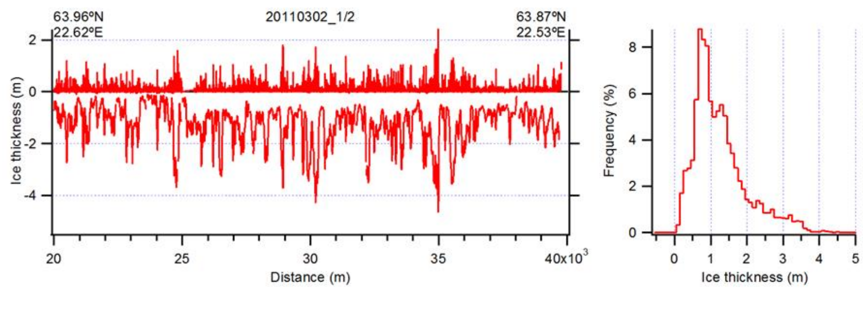

Figure 2: A 20 km section of combined surface laser profile and EM thickness profile, and the corresponding ice thickness histogram for the 2011 field campaign data. The laser profile resolves all ridge sails while the EM profile averages thickness over a altitude dependent footprint, typically 50 m.

P13 L 11 the 2 top figures of figure 5 appear to be the same.
The ridge density figure and the measured thickness values figure resembles each other very much, but a careful examination of the two figures reveals some small differences between the two. The very similarity between the two results from the high correlation between the measured thickness and the computed ridge density. More details are discussed in Section 4.1.

P13 L 9 and L 13 first you mention Table 1 and then Table 5 is this right?
There was an error. In both cases we referenced to the Table 2 (previously Table 1).

P13 L 15 histogram of Figure ?
Corrected. The reference is to the Fig. 6 (previously Fig. 4).

P13 L 25 64N 23E to SW → 64°N 23°E to SW???
Corrected to : 64°**N** 23°**E towards SW**

P14 L 8 values ?
A reference was missing which generated the question mark. The sentence is now as follows: ***For thin ice rather high σ^o_{HH} (over -18 dB) have also been observed (Mäkynen et al., 2004).***

P 14 even though a correction for incidence angle has been applied, there is still influence of the incidence angle on the response, especially for rough ridging ice this should also be part of the discussion on dB values: one should expect differences between near range and far range.

Based on the incidence angle correction methods studied in Mäkynen et al. (2002) and Karvonen (2002), the effect of the incidence angle on the level ice and ridged ice is minor for the σ^0_{HH}. For the σ^0_{HV}, after the incidence angle correction has been applied together with the noise floor correction in the range direction as in Karvonen (2015), there was not found any significant difference in the near-range and far-range values for either open-water, level ice or ridged ice classes, when visually inspecting the SAR images.

We agree that the incidence correction effect on the detection of level ice and ridged ice should be mentioned along with the backscattering statistics presented in Section 4.2. Therefore, we have added the following paragraphs in the Section 4.2:

"According to earlier studies the effect of incidence angle on σ^o for level ice and ridged ice is rather similar. In Mäkynen et al. (2002) it was found that the incidence angle dependence of σ^o_{HH} in logarithmic scale (dB) can be described by a linear model, with slopes -0.21 dB/degree for ridged ice and -0.25 dB/degree for level ice. It seems that using a slope of -0.23 for all the data is adequate for automated classification, and the ridged areas and level ice can be distinguished both at near and far range. Also a more sophisticated approach, iteratively applying different slopes for level ice and ridged ice has been studied in Karvonen (2002), but the effect on sea ice clas-

sification was minor. When inspecting the SAR mosaics visually most of the SAR frame boundaries were not visible or were hardly visible, indicating successful σ^o_{HH} incidence angle correction. For open water the correction may not work properly as for open water σ^o signatures depend heavily on wind speed and swell (i.e., surface roughness).

For HV channel, the combined incidence angle and noise floor correction is essential. Without this correction the HV backscattering and texture features derived from it can not be used in classification as the effect of the varying noise floor is so high (up to about 3 dB) and will cause a significant amount of misclassifications. However, after correction the HV channel data can be used in classification and we have not by visual inspection observed any significant differences in near-range and far-range σ^o_{HV} for either open water, level ice or ridged ice classes."

P15 L 23 whats a "had a correct mode ice class" ?
Sentence corrected to: "The ridged ice category (DIR 3) was correctly classified in 45 % of the cases but over 30 % of the observations were confused with level ice."

P 17 L 15-25 a bit of wishful thinking in this section
We are not certain which part of the text is considered by the Reviewer 1 as "wishful thinking". We admit that our current algorithm may not be mature enough for operational use yet. This will require more testing with more data.

Conclusions: this part appears to be more badly written than the rest.
Also the Reviewer 2 had some concerns on this Section. Therefore, we have rewritten it partly and tried to focus the discussion and conclusions in a more clear and focused manner. The new text is included below.

"The Degree of Ice Ridging is one of the most useful parameters for ice navigating ships. It basically indicates, together with ship characteristics, whether a vessel can safely pass through an ice field. The DIR also complements the more general Risk Index Outcome (RIO), defined by IMO (2016), as this does not address ridging but relies on WMO categories for the stage of development (age). We have shown here that an automated estimation of the DIR from SAR texture features, together with an ice concentration estimate, performs rather well when compared to the values extracted from the manual FIS ice charts. The applied features describe statistics of σ^o variation in the SAR imagery. DIR estimation is a suitable task for a SAR based approach because the C-band σ^o is sensitive to the large scale surface roughness due to ice ridging.

When we consider the purpose of the ice charts the fact that in the ice infested areas there operate both ships assisted by an icebreaker and independently navigating ships needs to be taken into account. In the Baltic Sea most of the merchant ships need icebreaker assistance. However, ships of the highest Finnish-Swedish ice class in the Baltic Sea, 1A Super, which is equivalent to the Polar Class PC 6, are

designed to operate in difficult ice conditions independently. The FIS ice charts are principally prepared to serve operations where ships follow an icebreaker in a convoy. Based on discussions with the FIS ice analysts the following remark is made. If the ice conditions in some area do not pose a realistic risk for icebreakers to get stuck, then in the FIS ice charts a smaller DIR values are often assigned to this area even when difficult for independent navigation by merchant ships. Especially this is true for DIR 2. Hence, the availability of the icebreaker assistance has some effect on the DIR classifications in the FIS ice charts. In addition the ice analysts cannot include all the details as the time for creating the daily ice charts is limited.

The primary objective of our DIR classification algorithm is to separate the severe ice conditions from the easier ones. To reach this goal our DIR classification mainly relies on the SAR image statistics. In some cases this may lead to differences between the FIS ice charts and our classification results because the FIS charts take into account the icebreaker factor not present in the SAR imagery. Hence, these two data sets can be interpreted from slightly different perspectives. An example of this difference is our earlier discussion related to Fig. 10 and Fig. 12. One essential advantage of the automated DIR charts is that they include leads and small level ice areas between ridged not present in the coarser FIS charts.

We used a two-stage classification system. First, we segmented the dual-pol SAR mosaics. This succeeded slightly differently for different months. The area by level ice always exceeded 50 % of ice cover. In January it was highest, over 70 %. In that month 93 % of the segmented area belonged to the segments dominated by one ice category. In February and March the respective figures were 80 % and 86 %. It should be noted that for January only three DIR categories were present, unlike for the last two months where all four DIR categories appeared. We can conclude that the SAR signatures matched the DIR boundaries best in March when the amount of ridging in our test period was at its maximum.

In the second phase of the classification we classified the segments using segment-wise feature vectors, classifying each segment to one ridging category. This succeeded best in March (82 %). Then the ridging intensity varied largely in different regions in our test area and the resulting texture of the SAR imagery was more versatile than in the other studied months. It is worth noting that in March the accuracy of the feature based classification was just five percentage points lower than the total area of the well-defined segments, i.e. the feature based classification succeeded with the RF classifier. This result can be regarded as a confirmation that the computed features were well suited to describe the ridging in the SAR imagery. In January the classification accuracy was at the same level as in March (83 %) but the area covered by the well-defined segments was much larger, indicating that the feature based classification did not perform as well as in March. In January and February the ice cover was rather thin and the degree of ridging lower than in March. Actually in these two months the σ^o_{HH} and σ^o_{HV} distributions from level ice and

ridged ice overlapped substantively. Partly this weak discrimination between level ice and ridged ice can be attributed to the subjective interpretation of the level ice category at FIS as discussed earlier in the Section 2.4.

Considering our classification results it seems that at C-band the proposed approach seems to work best in the Baltic Sea when the evolution of the winter has passed the freezing phase and a significant amount of ridging has occurred. Then ridging very strongly contributes to the texture of the SAR images.

Before setting up an operational DIR estimation system over the Baltic Sea, we still need to test our algorithm with more winters and to optimize it for the best possible result. In an operational mode we can use the most recent SAR/FIS and IC data for the training. Instead of using the SIC present in the FIS charts we can also use an automated radiometer or combined radiometer/SAR based SIC. Currently, the finest resolution in operational SIC products is offered by the Advanced Microwave Scanning Radiometer 2 (AMSR2) based ASI sea ice algorithm (Beitsch et al., 2014). The grid size in the product is 3.125 km. To improve our product during ice forming or melting periods, we can include ice thickness as an additional parameter in the future DIR classifications.

Our algorithm can be extended for use in the Arctic Ocean, where there is a higher demand for reliable ice information for independently navigating merchant vessels. Also, as harsh ice conditions as our March 2013 data prevail a much longer time period in the seasonal ice regime. An automated DIR chart utilizing the fine resolution (100 m or higher) SAR data and classifying the suitability of different areas for navigation would significantly benefit all Arctic shipping. For example, in the coming years Kara Sea year-round shipping will significantly increase because of the high volume liquefied natural gas (LNG) production and transport in the Yamal Peninsula. For Arctic sea areas, however, the algorithm would be more difficult to validate without knowledge of the true areal DIR values. The current Russian AARI ice charts only contain the general WMO sea ice categories without any indication of DIR. It is expected that our high resolution sea ice model to be implemented for the Kara Sea (Dr. Andrea Gierisch, FMI, personal communication) will be helpful in the development of an automated classifier. One alternative would also be to use the Baltic Sea ice data as a first trial to train the algorithm for the Arctic conditions."

References: I saw quite a few errors including in some of the titles, authors names. One has to be careful while copying and pasting references taken as is on the Internet; they are not always reliable.

We have corrected the errors found in the References section; we hope that there will not be any more errors left uncorrected.

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