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# *Interactive comment on* "Estimation of Arctic Land-Fast Ice Cover based on SENTINEL-1 SAR Imagery" *by* Juha Karvonen

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Review of Estimation of Arctic Land-Fast Ice Cover based on SENTINEL-1 SAR Imagery, Juha Karvonen by Valeria Selyuzhenok General comments: Overall, most of my comments were considered. The manuscript has improved after the revision. The methodology is presented in a more clear way and the new figures allows for easier evaluation of the methods performance. This new information triggered additional questions. Please, consider the following comments:

Thank You for the comments, in the updated version and this reposnse I have tried to address all Your comments. i hope the clarity of the manuscript has improved from the previous version.



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Discussion paper

1. The introduction presents a short overview of landfast ice studies including different methods of fast ice detection. It is not clear why a new method is required and how it would contribute to scientific progress. I suggest to add few sentences clearly describing the objective of this study. Page 2, lines: 31-33: “The algorithms proposed in this study are used for creating daily time series of the Kara and Barents Sea LFI extent in high-resolution gradually complementing the existing Arctic LFI time series derivable from Arctic operational ice charts.” It should be clear to the reader why it is important to produce daily (not bi-weekly or weekly) data set and in what sense the new data set would complement operational charts?

The daily products are produced because also other FMI sea ice products (sea ice thickness and concentration) over the are are daily (operational tests have been made during a few winters and they are continuously run daily) and the spatial resolution also better corresponds to our products. And we have plans to utilize the LFI estimation in our ice thickness estimation, thus a daily product in high-resolution is useful for us. For more detais, see my responses later.

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Doesn’t actually FMI-B produce 2-weeks average fast ice product?

Not exactly, FMI-B provides the areas which have been classified as LFI in each day of the two week period. FMI-B can be used to identify the areas which very likely represent LFI. Parts of LFI areas will be missed by FMI-B, however. It looks that in most cases the LFI detected by FMI-B are the same areas but the areas are smaller than for AARI ice charts or FMI-A. Thus FMI-A is preferred to be used for daily LFI detection. However, FMI-B could be used if we want to locate the only static (LFI) with a very high confidence and not include areas which have a bit lower (but still high) likelihood of being LFI (according to the automated algorithms).





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2. The methodological section has improved, but I find it a bit difficult to follow. I suggest restructuring the section in the way that it consecutively describes each step of the algorithm as they indicated in Figure 3. Please, avoid duplication: the paragraph on page 5 starting from line 10 seems to be an extended version of the text on page 4, lines 17-28.

I have updated the description and included references to Fig. 3 in the text. Also tried to remove repetition.

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3. Discussion and conclusions require major modification - Misleading interpretation of the results Without knowing the purpose of the study, it is difficult to judge whether the performance of the developed methods is good enough. For some purposes it might be important to know that probability of fast ice presence in the detected area is very high. Than, indeed FMI-B method would be more reliable, compared to FMI-A. However, FMI-B product would be irrelevant to quantify changes in fast ice cover, since it detects only half of fast ice area.

We at FMI think that FMI-A algorithm results are good enough to include the LFI detection in the operational FMI Arctic and Baltic products and to use the LFI also in improving the ice thickness estimation in these areas. This is true especially during the winter months (approx November-April). FMI-B was included here just as a reference, it may have applications in combining the two methods in an optimal way in the future (depending on funding and other future resources, unfortunately the EC HORIZON-2020 SPICES project funding used for this study has already been used and in that framework it is not possible to perform additional devleopment) The purpose of the study is also related to the automated sea ice products based on combined ice modelling and data from multiple EO input data sets, for more details, see my responses later.





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Page 8, line 21: “FMI-B can then be considered as an algorithm locating the LFI areas with a high confidence.”

Have changed this sentence to indicate that "FMI-B can be considered as an algorithm locating only the areas which very likely represent LFI." I hope it is more clear this way.

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FMI-B algorithm systematically underestimates the LFI area (Fig. 9, Tab.1). It shows only 50% of fast ice presented on operational charts. The author also mentions that fast ice edge location is not presented correctly compared to AARI charts (page 6, lines 28-30). I assume that at this stage, the algorithms can not be considered as a reliable method to map fast ice operationally. I recommend that further improvements (e.g. suggested by the author on page 10, lines 6-11) are made in order to provide more reliable operational data.

Unfortunately FMI does not have resources to make this kind of algorithm development studies/work now as the SPICEs funding for the related WP has ended. We think the results are useful and we are going to apply FMI-A in our operational tests and studies. Our aim is to include LFI detection in our operational framework both in the Baltic Sea and in the Arctic study area in the first phase. Wea re curently estimating ice thickness in Baltic and in the Arctic study area. In the Arctic study area we use TOPAZ-4 model as a background information, but the TOPAZ data has not proved to be very reliable and in the future versions we are going to include radar altimeter data (Cryosat-2) and use the FMI thermodynamic model HIGHTSI in the static ice areas during the static periods to estimate the themodynamic growth/melt in these ice fields to get good estimates of ice thickness. This has already been tested over the Baltic Sea LFI during the winter 2017-2018. We have studied the use of HIGHTSI model and SAR data in ice thickness estimation in multiple enclosed or semi-enclosed sea areas (such as Baltic Sea, Caspian Sea, Gulf of St. Lawrene and Bohai Sea) with promising results.





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However, in a non-enclosed seas our aim is to apply HIGHTSI only over static ice areas (during their being static). The LFI will be produced daily in the similar manner as ice thickness and ice concentration (based on SAR and microwave radiometer). A new algorithm was needed to get LFI in the same spatial and temporal scale as the other sea ice products. It is true that these do not always give exactly the correct ice information, however, we at FMI think they would be useful in navigation and also could be used to assist the visual/manual ice analysis.

I have added some text (and references) on this in the introduction.

References related to combining SAr imagery and an ice model for ice thickness estimation:

Arctic sea ice thickness (SIT): Markku Simila, M. Makynen, J. Karvonen, A. Gegiuc, A. Gierisch MODELED SEA ICE THICKNESS ENHANCED BY REMOTE SENSING DATA May 2016, Conference: Living Planet Symposium 2016

Gulf of St. Lawrence SIT: J. Karvonen, B. Cheng, T. Vihma, M. Arkett, and T. Carrieres, A method for sea ice thickness and concentration analysis based on SAR data and a thermodynamic model, The Cryosphere, v. 6, pp. 1507-1526 (http://www.the-cryosphere.net/6/1507/2012/tc-6-1507-2012.html), 2012.

Caspian Sea SIT: Karvonen, J.; Cheng, B.; Vihma, T. Estimation of Sea Ice Parameters Based on X-Band SAR Data and Thermodynamic Snow/Ice Modelling for the Caspian Sea. In Proceedings of the International Conferences on Port and Ocean Engineering under Arctic Conditions (POAC'13), Espoo, Finland, 9–13 June 2013; Available online: http://www.poac.com/Papers/2013/pdf/POAC13_029.pdf (accessed on 3 May 2018).

Balti Sea SIT: J. Karvonen B. Cheng, M. Simila, Ice Thickness Charts Produced by C-Band SAR Imagery and HIGHTSI Thermodynamic Ice Model, Proc. of the Sixth Workshop on Baltic Sea Ice Climate, pp. 71-81, Lammi, Finland 2008.

Bohai Sea SIT: Juha Karvonen, Lijian Shi, Bin Cheng, Markku Similä, Marko





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Mäkynen, Timo Vihma, Bohai Sea Ice Parameter Estimation Based on Thermodynamic Ice Model and Earth Observation Data, Remote Sens. 2017, 9(3), 234; https://doi.org/10.3390/rs9030234 https://www.mdpi.com/2072-4292/9/3/234/pdf (accessed on 3 May 2018).

It should also be taken into account that very also the AARI ice chart LFI includes some kind of error sources and inaccuracies. One definitely comes from the fact that the whole Arctic is a large area and an ice analyst is not able to make as accurate (e.g. 500m pixel size) analysis as a computer over such a larger area and the drawn polygons tend to smooth the boundary lines of different ice fields. It is also a fact that diffrent ice analysts see the ice situation in their own ways and there are differences between the ice analyses depending on the ice analyst (this was shown for sea ice concentration in the paper based on an experiment made in the IAW-2014 workshop). An algorithm provides systematical estimates and eliminates the variability due to possible varying interpretations and skills of different ice analysts.

Also added some text on this.

Reference with some information on the differences in analyzing the same ice field sea ice concentration (SIC) by separate ice analyst groups (not even individuals, probably producing even more deviating SIC information:

A comparison of SIC estimates provided by different ice analyst groups: Juha Karvonen, Jouni Vainio, Marika Marnela, Patrick Eriksson, Tuomas Niskanen A Comparison Between High-Resolution EO-Based and Ice Analyst-Assigned Sea Ice Concentrations, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, v. 8, n. 4, pp. 1799 - 1807, 2015 DOI: 10.1109/JSTARS.2015.2426414

Included this here just to indicate that different ica analyst produce different results (in the publication for SIC but very likely also for polygon boundaries and the other ice properties within them).





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- Missing references

Page 9, lines 12-22: Comparing the presented method with other studies, the author does not provide any references. Please, refer to literature to support your conclusions.

Some references are already given in the intro section. I added some references in this section to indicate which specific methods were considered here.

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- Redundant information Page 7, line 13– page 8, line 2: The comparison of air temperature measurement from the Longyearbyen weather station with variations in annual fast ice development neither belong to this methodological paper, nor present relevant scientific results. Linking 2 years of fast ice annual cycle with air temperatures measured 1500 km away from the study area does not make sense to me. First, there are several studies investigating fast ice development in the Kara Sea (Divine et al. 2003, 2004, 2005; Olason 2016) which indicate that air temperature is not the only factor controlling fast ice cover. Second, data from the Longyearbyen weather station are not representative for the study area because it can be affected by different atmospheric circulation regimes. To use such data, the authors should first prove that at least the atmospheric circulation over Svalbard and the Kara Sea were similar during the season. It might be more reliable to use reanalysis data. I recommend removing these paragraphs.

I have updated and shortened these paragraphs. I also studied the NCEP/NCAR reanalysis air temperature data at two locations, one in the southern Kara Sea and another in the northern Kara Sea. The temperature time series during the study period in the northern Kara Sea were quite similar to those of Longyearbyen, in the south some warmer during the summer, but the mostly including the same (warmer and colder) periods as for the two more northern locations. These all three indicate that the win-





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ter 2016-2017 was more severe than winter 2015-2016, and also the LFI extent was larger for the more severe winter of 2016-2017. It should also be noted that the stydy area is not only limited to Kara Sea but also the Svalbard area (and Longyearbyen) were included in the study area. Lonyearbyen was selected because the data were available. Unfortunately, we do not at FMI have access to Russian measurements. It would be nice to discuss with the Russian institutes of future research co-operation also including data sharing with each other. I think it would be a benefit for both.

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4. In general the text is difficult to read. I feel that the English may need improvements.

I have tried to check and further improve the language. The other reviewer was a native English speaker and he was able to understand my English. There may be some details needing correction, but I hope this will be possible in the final editing phase (if the manuscript will be published). If found necessary by the TC editor, a proofreading service can also be used for the final version.

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Specific comments:

Page 1, lines 23-24 – page 2, lines 1-2 : The part regarding fast ice modeling was marked for improvement during the interactive discussion. It has became even more confusing. It is not clear why author starts talking about fast ice thermodynamic and dynamic modeling. The paragraph does not seem to bare any relevant information. I suggest clarifying the message and including references to modeling studies or removing the entire paragraph.

I have tried to clarify the context. We have plans to apply a thermodynamic ice model over the static ice fields to estimate ice thickness. We have done this over the Baltic Sea succesfully during this year's winter. We'll continue the Baltic work next winter and will provide an operational Baltic LFI service demontration (a CMEMS downstream ser-





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vice BALFI). After the season 2018-2019 we'll also be able to provide some accuracy comparisons over the Baltic, but it will be a topic of another publication which will also involve a detailed description of the service demontration still partly under construction.

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Page 6, lines 7-8: The FMI-B underestimates LFI, compared to AARI charts (Table 1, Figure 9). It doest not seem to perform better, than FMI-A. Although FMI-B produces less false positive estimates, the number of true positive is also reduced. Would FMI-A produce similar results applying higher threshold?

It is true that FMI-B produces significant underestimation of LFI. It can possibly be used to locate the areas of LFI which very likely represent LFI. Possibly it could be then combined with LFI-A to gro the LFI-B LFI areas e.g. by those areas of LFI-A which are connected to the LFI-B areas (region growing). This will be a topic of future research depending on resources available. currently no resources for further Arctic LFI studies exist, the only thing we can do is torun and update the time LFI series ob ftp.

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Figure 8 : It is not clear to me what is shown in (c).

It gives the relative amount of LFI in AARI ice charts during each month of the year. This is to help to interpret the other subfigures, e.g. in June there were about 5% of the total LFI and in July only about 2% of the total LFI grid points, so even though there were more erroneous classifications compared to AARI ice charts during these months, their contribution to the total error was small compared to winter months with over 15% of the total LFI grid points. These are simply computed as (monthly) percentages of the sum of the whole LFI areas of the one year period AARI ice chart LFI. I have added an explanation in the caption.

Also corrected an error in the y-axis labels, there should naturally be "5" and "10"





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instead of "0" and "5", this may also have caused problems with interpretation of the figure.

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Figure 10 : What are the boarders of the regions (SW, NW, Ob)? Why do these regions come into play? It would be more useful to provide the curve for the entire area to compare it with the AARI data.

A sub-figure indicating the area division used has been added. This is just to enable comparison to the results of the given reference using this kind of division. Unfortunately, inclusing more AARI data would require much work with the data and we do not have the resources for this work now (the supporting project SPICES is ending and no more work related to this WP of this project can be made any more).

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Technical comments: The text requires careful proofreading to exclude typographical errors

I have perfomed spell checking and tried to improve the language.

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Thank You! Juha Karvonen, FMI

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