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The Cryosphere Discussions

Interactive comment on "On the statistical properties of sea ice lead fraction and heat fluxes in the Arctic" *by* Einar Örn Ólason et al.

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Review of "On the statistical properties of sea ice lead fraction and heat fluxes in the Arctic" by Olason et al. by Nils Hutter

In the manuscript, the authors use the statistical properties, heavy-tails and spatial scaling, that have been previously used to study the localisation of sea-ice deformation to study the lead density simulated by the sea-ice model neXtSIM and observed from satellite. The authors find that both agree with respect to these statistics. Furthermore, the model is used to study the same statistical properties for simulated heat fluxes with the result that heat fluxes are strongly localised. This analysis contributes to the on-going research how important small-scale information of sea-ice (floes, leads and

pressure ridges) are for the interaction of sea-ice with the atmosphere and ocean. The paper is written concisely and I recommend it for publication if the following comments are addressed.

General comment:

The authors choose rather complex statistical tools by analysing the heavy-tails of PDFs and the spatial scaling. These methods are appropriate to study the localisation of lead density and simulated heat flux, which is the main topic of the manuscript. However, a comparison of the spatial distribution of lead density as done in Wang et al. (2016) and Hutter & Losch (2020) is missing, although all data would be available for that. In Fig. 1 such a comparison is made for a snapshot of a single day. I recommend to add a comparison of spatial distribution of lead-density for the entire winter analysed in this paper (maybe replacing Fig. 1). In doing so, the model evaluation of this manuscript would be more comprehensive by showing that the model (might be)/is able to reproduce the large-scale spatial distribution and the strong localisation of lead-density.

Specific comments:

P2, line 32: "Andreas and Cash (1999); Esau (2007)" - wrong citation style

P2, line 35: "including smaller leads increased by 55% the total estimated heat flux" - including smaller leads increased the total estimated heat flux by 55%.

P2, line 35-37: I assume that the magnitude of the overall heat flux is adjusted by the tuning of thermodynamic parameters in coarse resolution climate models. However the spatial distribution and local magnitude might be off, if leads are not resolved in these models. Please clarify.

P2, line 48-49: "the statistical properties of leads in large-scale sea-ice models have not yet been shown to be robustly reproduced" - How about Wang et al. (2016) and Hutter & Losch (2020). Wang et al. (2016) shows agreement in the lead density in the Arctic

between a model simulations and satellite observations. Hutter & Losch (2020) show that multiple spatial and temporal properties of LKFs, which are leads and pressure ridges, observed from satellite are matched by large-scale sea-ice simulations.

P2, line 61: “Section 2.1” - Section 2.1 presents only the model set-up. Please refer to Section 2.

P3, line 61-70: This paragraph reads a bit wordy. Maybe consider to rephrase it.

P3, line 83: “model mesh” - Model mesh or the mesh to which the model output is interpolated?

P4, line 1-2: Not clear, from which data product concentration and from which product thickness is taken. Please clarify.

P5, l 125 “order” - order -> orders

P5, l 136: “2011” - 2011 vs model year 2007? In the model description it is written that the model is ran for winter 2007, later on in the paper you evaluate only the year 2011. Please clarify. Does this sentence anyways not rather belong to the results section?

P5, l150: “PÌĎ âĹij L$-\beta$(0)” - Supposing x_bar should represent the mean, it should be beta(q=1). For q=0 no scaling should be observable, if equation (2) is used (xˆ0=1 for all samples).

P6, l152: “Stern et al. (2018) argue that this method provides a reasonably accurate estimate of the power-law fit.” - In addition, Stern et al. (2018) argue that no matter what method is used for estimate of the power-law exponents a goodness-of-the-fit test like in Clauset et al. (2009) should be performed. Please clarify, if you do such a test, or why it is not necessary in this case.

P6, l153: “might provide” - Replace by “provides”. Both Stern et al. (2018) and Clauset et al. (2009) say it provides better estimates. Given that the method is computationally not much more expensive, it is unclear to me, why you choose to use a more inaccurate

method.

P6, l171-172: “It is important to note that the simulated lead fraction is not strictly a lead fraction as it includes all open water areas, including polynyas (cf figure 1).” - How about using a smoothened concentration field to mask large open-water areas as around Svalbard?

P6, L 177: “showing a deviation from linearity at around 70%” - I can not see a clear deviation. Is it due to the dashed line style. An annotation to the plot could help to point the reader to what you mean.

P6, l178: “When excluding this region, the observations also show a linear decrease (Fig. 2, solid blue line).” - This does not fit to the caption of the Figure2 (dashed for “Arctic” and solid for “Central Arctic”).

P6, l 182: “However, we suspect that the large number of small leads forming there may result in increased noise in the lead fraction product (see Fig.1) and an overestimation of the large lead fractions.” - Not clear to me. Please be more specific why more small leads lead to an overestimation of the lead fraction product. Or do you mean that by having many small leads the lead fraction increases, but the model does not resolve these small leads and therefore shows lower lead fractions?

P8, l197: “than 20%” - Add (note shown) or reference to figure.

P8, l 203: "strong indicator" - Be cautious, even if the scaling is right, the regional distributions could be off, i.e. high lead fractions found close to the coast or in Beaufort sea in observations could be reproduced by the model in different regions. To clarify this, please be more specific what you mean with lead-fraction patterns in the text.

P11, l 243: “In addition to these differences in the scaling, there also seems to be a difference in the nature of the structure function, depending on the model resolution” - Please also discuss the change in structure function for the lead fraction. It appears that the linear fit is not appropriate to fit the structure function of the coarse resolution

models (The fit does not pass the uncertainty interval for q=1).

P13, l267-269: “We also assume that the closing is directly proportional to the area of the polynya since most of the heat loss and ice formation happens over open water.” - This assumption is not clear: I agree that ice formation is larger over open water, but if a polynya is formed instantaneously the entire area of the polynya starts to freeze at the same time. Please clarify.

P14, l 219: “figure 4” - Please reference the subfigure for clarity.

P15, l300-308: “This is partially due to the fact that neXtSIM . . . the lead-fraction and heat-flux scaling and structure functions across different model resolutions.” - This paragraph is not clear to me. It is difficult to follow your line of argumentation. Please revise and rephrase.

P16, l320: “Conclusions” - You provide rather a summary of the paper than a conclusion. So, please change the title of the section accordingly.

Data and code availability: A statement is missing, where to find the code and data of this study.

Figure 1: “Lead fraction larger than 0.05 is indicated in yellow.” - Why do you show the thresholded fields instead of using a colormap that highlights the 0.05 fraction about shows the entire range of lead fractions? I recommend to use a show the entire range of lead fractions.

Figure 2: “The dashed straight lines are linear fits discussed in the text.” - Could you use color to indicate which fit belongs to which data. Please use different linestyle for the fits and the “Arctic”. Please also add all lines to the legend to clarify. In the caption “Arcitc” should be “Arctic”.

Figure 4. Please add (a) and (b) labelling to the subfigures.

Figure 7: “he” to “the”. How do you choose the order of the polynomial fit of the

structure functions here? For 12.5km and 25km the linear fit does not seem to be appropriate to fit the structure function, but rather a higher order (quadratic?) is required. This, however, would mean that the lead fraction gets multifractal for higher model resolution. Please elaborate on this difference when changing the model resolution in the text.

References:

Wang, Q., Danilov, S., Jung, T., Kaleschke, L., and Wernecke, A.: Sea ice leads in the Arctic Ocean: Model assessment, interannual variability and trends, Geophys. Res. Lett., 43, 7019–7027, https://doi.org/10.1002/2016GL068696, 2016.

Hutter, N. and Losch, M.: Feature-based comparison of sea ice deformation in lead-permitting sea ice simulations, The Cryosphere, 14, 93–113, https://doi.org/10.5194/tc-14-93-2020, 2020.

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