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Interactive comment on "A lead-width distribution for Antarctic sea ice: a case study for the Weddell Sea with high resolution Sentinel-2 images" *by* Marek Muchow et al.

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Answer to Anonymous Referee 1

We thank the editor Dr. Jenny Hutchings and the two anonymous referees for the helpful comments and their efforts reviewing the paper. Please find point-by-point answers to the comments below. The answers to the other referee and the editors note are separate comments.

Anonymous Referee 1

The manuscript aims to compare lead-width distribution estimates from an Arctic set-

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ting to an Antarctic setting. Within the manuscript a set of lead-width distribution algorithm parameter estimates are being calculated using a set of Sentinel-2 images. The algorithm parameter was found to be lower compared to the estimates for the Arctic sea ice areas. As the Antarctic sea ice areas are significantly less investigated compared to the Arctic sea ice areas the subject is interesting and timely. Unfortunately, the manuscript is poorly written and it's very unclear what the overall aim and the novel scientific contribution is.

Specific comments

It would be beneficial if the method is also used on a set of images covering the Arctic sea ice to see if the change in parameter setting relates to the Antarctic conditions, the method or the satellite data. In the Abstract it is stated that you compare exponents from the Arctic sea ice that do not agree with each other to your estimates for the Antarctic sea ice. Why do the estimates from the Arctic sea ice not agree?
The estimates from the Arctic sea ice do not agree to each other as discussed in the manuscript. It is unclear if this is related to the fitting method or the underlying data set. For future comparisons the same fitting method should be applied to estimate the exponents. We agree that it would be interesting to analyze images from the Arctic. However, such an analysis was not within the scope of this study. We will include this point in the discussion an elaborate more on the (regional) differences of the exponents.

As far as I can understand the nilas areas include both open water and nilas. Please confirm. It is unclear why these two lead types are not separated from each other, and if this separation was done in the scientific work by others that the lead parameter settings are compared to. This needs to be clarified.
Yes, nilas is both open water and nilas. We do not separate these from each other since the water in leads refreezes quickly depending on the surrounding temperatures. But even when leads are covered with thin ice like nilas, they have properties that are characteristic for leads with regard to heat exchange, ice production and also being

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navigable by several surface vessels (see "WMO Sea Ice Nomenclature (WMO No.259, volume 1", 7.3 Lead). We will make that clearer in the new version by renaming the two thresholds and explaining the use of both thresholds. https:// library.wmo.int/ index.php?lvl=notice_display&id=6772#.YAgyIsJ7mUk (last access: 20.01.2021)

Why are leads with dark-gray sea ice (up to 10cm thickness?) and light-gray (up to 30 cm thickness?) sea ice not included in the analysis? It is specifically stated in the methods section that you are investigating threshold for four different sea ice types. Dot he studies compared to within this paper include those other sea ice types?
The surface classification are not connected to any measured thicknesses, since the Sentinel-2 Level-1C product only provides optical data, which is why the names correspond to the "grayness" of the ice. For the calculation of the lead with distribution we decided to focus on leads covered by open water or nilas only – mainly because previous studies also investigated leads with these surface types. This is necessary to make the obtained results more comparable. The other surface types could be used for different applications. We will clarify this in the corresponding sections.

A schematic figure outlining the processing steps would aid the reader to understand the different steps within your method. How are the classified images validated? How many different individual leads were used in this study?
In total, the number of leads is 2024 for the open water threshold and 3799 for the open water and nilas threshold. Thank you for the recommendation. We will create a schematic figure for describing the selection process of the images. We will include this one or a similar one in the data section (Section 2.) and will adapt the description of the method to enhance clarity. We also prepared two additional figures for the method section.

Overall the manuscript is poorly focused, many sentences difficult to follow and references to appropriate work is missing. The presented aim is the lead-width distribution however, the manuscript focuses on the algorithm parameter setting and not on the outcome of the lead-width estimates. Please either change the aim of the manuscript

or change the manuscript to reflect the aim.
We will revise the manuscript according to your detailed suggestions below. Regarding the focus, we will clarify that the ice type and threshold detection is only a prerequisite, which is necessary to identify leads. The main aim is then to use these leads to obtain a lead width distribution. We will adapt the corresponding section accordingly.

Technical corrections

Why was the Weddell sea picked for this study? Does it have a high/low frequency of leads compared to other areas of the Antarctic sea ice areas? Work by e.g. Willmes and Heinemann (2016) have indicated that different parts of the Arctic Ocean have different regional characteristics.
The Weddell Sea was chosen for its special scientific importance, its size, the size of the sea-ice cover during November to April and availability of cloud free images in the Southern Ocean. Furthermore, Sentinel-2 is a land mission and images over ocean are only available in the vicinity of land which restrict the regional selection. We will discuss that results from the Weddell sea are not necessarily representative for other Antarctic areas. We will include the Willmes and Heinemann (2016) paper for comparisons and further assessment of our results.

P1. R4-5. Unclear sentence please revise. *Will be changed.*

P1. R7-8 after the comma is a repeat of what was said on row 4-5. Please remove. *Will be changed.*

P1. R12. Replace bigger with larger or greater than *Will be changed.*

P1 R21. Please insert a reference. *Will be fixed.*

P2 R34. How wide is a very narrow lead? *The "narrow lead" refers to the high resolution of 10 m of our study.*

P3 R4-5. Unclear sentence please revise. *Will be changed.*

P3 R6. Insert references to these studies. *Will be fixed.*

P3 R13-14. This is better suited in the discussion. *We agree.*

P3 R21. Are you using data from November to February or November to April? The way this is written now is confusing.
The sentence will be rewritten. The data is always part of the months between November to April, while being from the overall time period of November of 2016 to February of 2018.

P4 R5. This section deals primarily with identifying thresholds and not classification of surface types. Consider changing the title. Moreover, the classification step is done in section 3.2 and should be reflected in the title there. I'm sorry but I could not follow how the lead width information was extracted from the images. Please clarify this.
The section 3.1. will be renamed in a way that indicates the topic of "threshold identification". The lead width information was conducted in a following way: 1.) A binary image was created with the threshold (see Figure 3), then a measurement grid was put on top of the image consisting of 10 vertical and horizontal measurement tracks, which have a distance of 10 km to each other. The lead width is then measured across each track with counting the pixels (black in Figure 3 for indicating a lead), which then refers to the width of the lead.

P4 R9. Unclear sentence please revise. *Will be revised.*

P4 R16-18. Unclear sentence please revise. *Will be revised.*

P4 R28. Not only nilas but also open water. *Yes, the thresholds will be renamed for clarity.*

P4. R30. What is apparent lead width? Please define.
The "true lead width" would be measured if every lead width was measured orthogonal to the lead. Our measurement grid can not guarantee that, which means that we sometimes measure not the shortest width but the width of a line across the lead with

an angle other than 90 degree. That is why we call the lead width "apparent lead width" similar to Wernecke and Kaleschke (2015) . This will be stated more clearly in the text.

Figure 2 Consider indicating the different TOA-reflectance areas that results in the different ice types, e.g. introduce a gray scale indicating classification areas. At the moment this figure is difficult to understand.
In this figure we do not show the classification of different ice types, but rather use a single threshold (open water or open water/nilas) to distinguish lead and sea ice areas. This results in a binary image (black for lead and white for ice) and thus introducing a gray scale colormap would not be helpful here. We will improve the figure caption to make this more clear.

P5 Figure 3 text. What does "The swath does not cover the whole image area" mean? Either the Sentinel-2 image exist or not. Should image area be study area?
The Sentinel-2 Level-1C products are always 100 km x 100 km products, but the swath of the satellite represented in the product does not always cover the whole area of the product, which is why the bottom right corner in the upper Band 4 image has a solid white triangle. To clarify, we will replace "image area" by "figure area".

P4 R30 -P5 R1. Unclear sentence please revise. *Will be revised.*

P6. R2. What is $x_width?$ *x_width is the measured apparent lead width.*

P6 R3. Where did the values for parameter C come from? This needs to be clarified.
The parameter C is the offset at the y-axis of the function and is therefore related to the number of measurements.

P6 R13-14. Please add the 10m to the equation, or specify how the 10m were added to the equation.
The 10 m were added for the variable "step size", since the 10 m indicate the step size of the measured lead widths.

P6 R17-18. This section is not results but should be put in the method or data section.

In Section 4.1 we use the thresholds determined using the method described in 3.1 and compare the resulting reflectances to albedo values from the literature. Thus, this is rather a discussion part - which we decided to combine with the Results section to improve the readability of the manuscript.

P6 R30. References missing. *Will be fixed.*

P6 R29-30. Do the TOA values reported here also correspond to the values for the Arctic sea ice? The comparison here appears to be only for Antarctic data.
As we stated above, this would be interesting to investigate in the future but is beyond the scope of this study.

P7 R6. Compared to what? Figure 5 is difficult to see. As the discussion primarily revolve around the for the two different methods for the two different mediums, why not combine the open water areas in one figure and indicate the different methods in the legend? Or better yet combine everything into one figure for easier interpretation. Consider also changing the color scheme as the colors are too similar and it makes it difficult to analyze the figure.
We disagree with putting everything (4 lines, two data sets) into one plot, since the lines then tend to overlap and the figure is crowded and it becomes difficult to understand the fine differences. We decided to create 2 figure panels for each of the two question of the problem. 1) The influence of the applied fitting method on the same data set, which is Figure 4. Figure 4 shows the combination of both methods only for the open water threshold (left figure) and only for the open water and nilas threshold (right figure). 2) The influence of the used threshold on slightly different data sets, where we can see that for example the influence of the data set for the ML method is really small. These nuances would be more difficult to highlight in one combined image.

P8 R7-8. Unclear sentence please revise. *Will be revised.*

P9 R6-8. Unclear what you are trying to say here. Please discuss why different results are achieved and what this means.

Here, "results" refers to the different power law exponents in the literature. We will extend the discussion of the differences of the results and what this can mean for future investigations.

P9 R24-26. According to Table 2 the resolution of the Wadhams papers are 5m. It is unclear what you are saying here. Please revise.
The Wadhams studies did not use satellites, but submarine missions, thus their possible spatial coverage is smaller. The advantages of satellite data are the increased spatial coverage and repeated overpasses. Here, we wanted to highlight the high spatial resolution of Sentinel-2 and the possible advantages compared to other satellite products.

P9 R34-35. Please specify what these other data sources could be.
Since Sentinel-2 only provides optical information a combination with field measurements for the validation of the surface types would be beneficial.

Section 4.3. This section does not belong in the results but should be moved to the data section instead.
We will move this section to section 2. Methods.

Table 2. The table needs to be updated so that it is clear to the reader that the two values reported in the present study are for open water and nilas+open water areas. It is unclear from the present manuscript what the other reported values have used as criteria for their power law estimates? Are these values reflecting values for open water, nilas or leads generally? For the two different thresholds used in Marcq and Weiss (2012), do they also separate into two different lead types or are the two values a result of two different methods? If it is the latter please separate the values reported in the same way as is done with the present study results.
We will update the table to make the differences between the results more obvious. Marcq and Weiss (2012) used two different thresholds for leads (with open water) based on two different luminescence thresholds.

Reference Willmes S. and Heinemann G, (2016), Sea-Ice Wintertime Lead Frequencies and Regional Characteristics in the Arctic, 2003–2015, Remote Sensing, 8(1),4,https://doi.org/10.3390/rs801

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