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Interactive comment on "Observations of Sea Ice Melt from Operation IceBridge Imagery" *by* Nicholas C. Wright et al.

Nicholas C. Wright et al.

ncwright.th@dartmouth.edu

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* Author responses are denoted with a > before the paragraph. A PDF with changes tracked is included as a supplement.

Summary The authors provide an update to the Open Source Sea-ice Processing (OSSP) algorithm and apply it to the optical Digital Mapping System (DMS) images acquired during Operation Ice Bridge flight tracks flown in melting conditions. The OSSP derived relative surface fractions include ice, open water, and melt pond. Statistics on melt pond fraction are important for understanding sea ice evolution, light exchange, and for parameterizing models. The documented improvements to the OSSP are important since the code is being made freely available and potentially facilitates some standardization in the processing of high resolution optical datasets of sea ice during melting conditions.

In general the paper is well written and organized, and the output figures and tables concise and informative. The improvements to the OSSP are well documented, however there are some problems with the analysis of the output data from the OSSP applied to the optical DMS data from the Ice Bridge flights.

>Thank you for your review of our manuscript. You have provided some insightful comments that have helped us to improve this work. In general, we have made a number of changes to better include discussions of the temporal aspects to melt pond formation and to properly place our observations in the context of known pond evolution pathways. We have attempted to remove or lessen the more speculative discussion points in the original manuscript and better incorporated previous research that supports our analyses.

The assertion that, based on the analyzed data, first-year ice (FYI) often has lower melt pond fraction than multiyear ice (MYI) is misleading. There is insufficient data analyzed, and the temporal component of melt pond fraction evolution (including a comprehensive review by one of the co-authors) is mentioned but largely ignored for the purpose of supporting the assertion.

>We do not believe this is misleading. FYI and MYI have unique pond evolution, and it is expected that FYI will fall below MYI during certain phases of melt. According to the four stages of melt documented by Eicken et al. (2002), this happens during stage two, where FYI drains much faster than MYI. We have, however, removed the phrase "often" as we do not have the data to support this for the whole season. Observations at SHEBA found 10-30% of FYI to have zero or low pond coverage late in the melt season (Eicken et al., 2004), and our results (17%) fit right in the middle of this range.

Lines 288-293 describe the timing of the acquisition of the DMS images for this study as being in late in the melt season, when ponds have drained to sea level. In this case it can be expected that, for any sea ice that is still above sea level, the mechanically weak FYI will have likely drained and melt pond fraction will be lower than it is for MYI undergoing similar melting conditions. That is consistent with the stage of melting, not the overall behavior of FYI and MYI during melting conditions.

>At late stages in FYI pond evolution, any sea ice that is still above sea level is by definition unponded because no ponds exist above freeboard. We may be considering different definitions of a melt pond than you because we are approaching this from an albedo and radiative transfer perspective, where submerged ice falls into the melt pond category. This is consistent with prior research where on FYI the "melt pond fraction" steadily increases in stage 3 after FYI ponds have become fully connected with the ocean (Eicken et al., 2004, Polashenski et al., 2012).

>For illustration we have included a pair of images below. Panel A of shows FYI in an advanced state of melt that can be assumed to be thin ice with ponds that are fully connected to the ocean water, yet the surface is almost entirely flooded. Contrast this with Panel B, which was taken the same day just a few km away, where the FYI has very little pond cover.

The hypotheses in the introduction are therefore poorly stated, the analysis misguiding, and the resulting conclusions are flawed.

>The hypotheses are both presented in similar form in previous work (as cited in the manuscript). We have, however, attempted to make it clearer in our manuscript that our statement of these hypotheses in the introduction does not mean that we have confirmed them to be true. Quite the opposite! For example, we did not see sufficient evidence for the duality hypothesis and rejected it (as much as it is possible to do so with this dataset).

That FYI experiences greater melt pond fraction than MYI has been more than posited, as stated on line 55, it has been well studied in the context of sea ice geophysical evolution. The authors must analyze their data in the context of the fairly well understood temporal behavior of melt pond fraction evolution on FYI and MYI, and situate their observations in the correct context (late season), using ancillary data if needed. It would make more sense to present the data as is, and evaluate the OSSP algorithm performance, without the general assertions about FYI and MYI behaviors – this not detract from some very interesting results.

>We have made a number of refinements to better include discussions on the temporal aspects of melt pond evolution and remove assertions that are not sufficiently supported by the temporal snapshots provided with this dataset.

Other comments 1. In cases where the sea ice has melted to sea level, and the ice floats below sea level, that is ocean water and sea ice – not melt pond covered sea ice. Has this been correctly specified in the algorithm and resulting statistics? Consistent terminology regarding the season and stage of melt would make the paper clearer and easier to follow. For example, are spring conditions (line 86) actually spring when it is freezing conditions? The June 1st cut-off for categorizing freezing-melting conditions is arbitrary.

>Submerged ice is classified with the melt pond category following from the arguments in Wright and Polashenski, 2018. In short – we approach this from a solar radiation energy balance perspective where submerged ice is more similar to a melt pond in its radiative properties. Melted through ponds are classified as open water for the same reason. We have added these categorizations to the introduction and the terminology through the paper is consistent with these definitions.

>The June 1st cut off is arbitrary but is not important for the categorization. We have changed the description of the cutoff to be in reference to mean melt onset date from passive microwave datasets.

More information on the nature of the training data is required. It would be interesting if the algorithm could be trained to detect drained FYI (i.e. ice previously covered by pond which has then drained once connectivity with the ocean is achieved), since this ice has much different fluid and gas exchange properties compared to exposed ice.

>More detailed information on the training data is available in Wright and Polashenski, 2018, where this method was first presented. The training datasets here are larger but are the same in other regards as those previously described.

>The ability to detect drained FYI would be powerful but it is likely not possible from optical datasets. Drained ice in many cases does not look different than melting ice that never had a pond cover.

Once FYI and MYI are defined the full terms are not required.

>We have replaced the full terms with the abbreviations after the first use.

The assertion on line 225 is biased. Consideration of typical melt pond fraction conditions would include temporal domain, not just the spatial. This has been well documented. There could very well be low pond fraction if the FYI has drained and I would suggest that the sea ice community is aware of this.

>Bias implies some ulterior motive or misrepresentation to support a goal, which is not our intention. We agree that specifying the ‘typical’ melt pond cover on FYI depends on the temporal domain because the pond fraction evolves over the melt season and have therefore clarified our statement here.

>We have changed the phrasing in this section to include mention of the temporal aspect of pond formation. Our goal is to point out the prevalence of pond free ice observed in our dataset and to place this in context with previous studies, not to claim that pond free ice is a novel observation. Because our dataset is a snapshot in time we cannot determine if the pond free ice was the result of pond drainage or the result of ice that never formed ponds.

>We have also included references to previous work that have observed pond free ice.

Detailed Comments

L32: ‘fine’ detail instead of exquisite

>Changed.

L73-74: specify the extent i.e. ground coverage of the images

>Added this information.

L108-109: more detail on expanded training datasets is needed

>More detail is available in the publication that describes this technique. There is not much else to add beyond what is in that manuscript.

L145: Start this section by defining a pond-free ice area. Otherwise it is a bit confusing, as all areas of exposed ice (1-PF) are pond-free ice areas.

>We have moved the definition to the beginning of this section.

L185: “. . .the large the variability . . .” delete extra ‘the’

>Fixed.

L217-219: There has been much work done understanding the melt pond fraction evolution for FYI and MYI, and pond evolution is likely explained by drainage mechanisms in this late period.

>We have reworked this section to include more discussion of previous work and to place it into the context of known MPF evolution for FYI and MYI.

>Drainage is a possible explanation, but there is also the possibility that ponds never formed on this ice. We cannot investigate that from this dataset because there is no temporal dimension.

L269-277: Missing from this paragraph is the occurrence of late season FYI when ponds have drained but the ice is still above sea level. In this case, FYI pond fraction would be less than MYI (likely the case in Figure 10f, for example).

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Discussion paper

>We have added a few sentences here discussing times where FYI would be expected to have lower MPF based on previous studies:

“ These effects must be balanced with the times in melt evolution where FYI is expected to have lower MPF. In the early season, MPF on FYI tends drop faster than on MYI because the meltwater is able to drain to sea level at a faster rate (Polashenski et al., 2012), and in the late season thicker FYI pond fractions would be lower than MYI because the more of the level surface sits above freeboard (e.g. Figure 10d). ”

L282-285: There should be mention of diurnal variations in pond fraction due to variable meltwater input and drainage process which, for level sea ice, can lead to dramatic changes in melt pond fraction over very short periods of time. Subtle changes in air temperature or surface energy balance can predicate these changes in melt pond fraction.

>We have added discussion of diurnal effects on melt pond fraction to this paragraph.

L331-332: This hypothesis is not investigated in the paper since it does not utilize data from early stages of melt pond coverage, when ice is relatively impermeable and differences in melt pond fraction are related to topography hence ice type.

>We have rewritten this paragraph of the conclusions to fix this issue:

>“We have investigated snapshots of melt pond coverage differences between FYI and MYI in the Beaufort/Chukchi Sea region for 2016 and the Lincoln Sea for 2017. Our results support previous findings by X and Y that FYI can have lower pond fraction than MYI under the similar forcing conditions. While the results presented herein cannot definitively confirm or refute the hypothesis that FYI has higher mean pond fraction than MYI, the high variability in FYI pond fraction over large regions suggests that the general rule of thumb that FYI should have higher ponding than MYI is too simplistic. Furthermore, the finding that FYI exhibits much larger variance its evolution indicates that there is not one path that defines the typical evolution of pond coverage. We did

not find sufficient evidence that there is a strict duality in FYI pond evolution either, and we suggest future process studies investigate the mechanisms that drive FYI towards high or low pond fraction and [. . .] ”

L443: The blue color scheme for pond fraction is difficult to interpret in the figure.

>We have adjusted the contrast in this figure.

Please also note the supplement to this comment:
https://www.the-cryosphere-discuss.net/tc-2019-288/tc-2019-288-AC2-supplement.pdf

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Interactive comment on The Cryosphere Discuss., https://doi.org/10.5194/tc-2019-288, 2019.

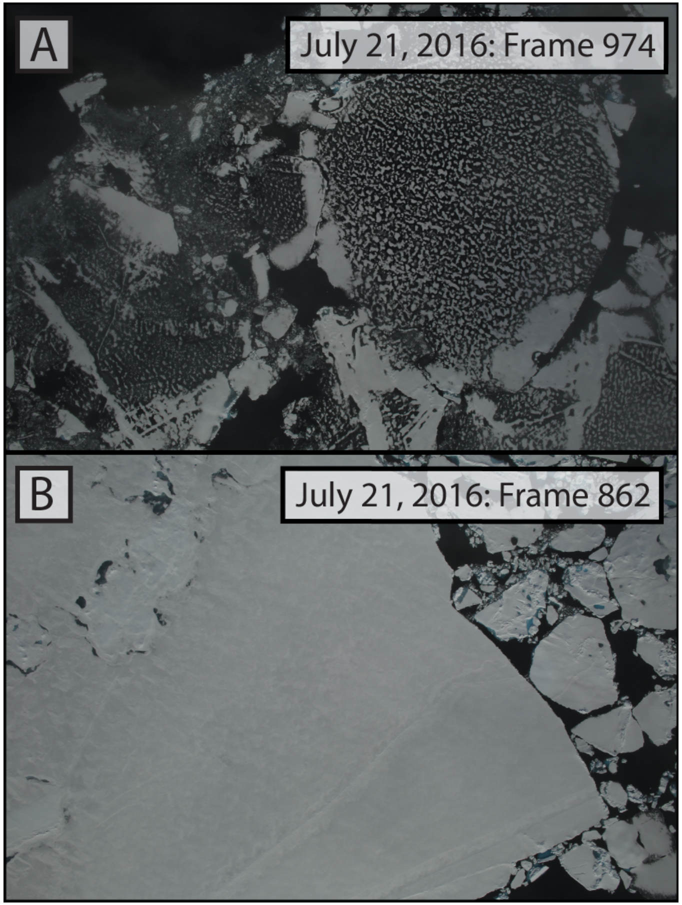

Fig. 1. Example of pond free and high pond cover ice in close spatial proximity.