

The Cryosphere Discuss., author comment AC1
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Reply on RC1

Grant J. Macdonald et al.

Author comment on "Evolution of the Amundsen Sea Polynya, Antarctica, 2016–2021" by
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Dear Reviewer 1,

Thank you for your feedback and the time you took to review our paper. We appreciate your criticisms, which will help us make the paper clearer if the editor gives us the opportunity to submit a revised version. Below we outline our initial responses to the points you made. We will provide more detail regarding specific changes if/when submitting a revised version of the paper.

The question is whether the low SIC area of <70%, which is more extensive than the footprint size (>5 km) of the passive microwave radiometer, can appear in the Antarctic coastal region in winter when the weather conditions are very cold and windy. Under such conditions, even if an open water fraction does appear, it will soon freeze up and be covered entirely with new frazil (grease) ice, except for very close to shore where divergent ice motion is prominent. In SIC algorithms for passive microwave radiometer data, especially early ones, it is known that the SIC of thin (new) ice is underestimated. This is caused by the polarization ratio (PR) of the brightness temperature used in the algorithm: the PR value of new ice is similar to that of open water compared to that of first-year ice (Cavalieri et al., 1994). In addition, the PR value of landfast ice is similar to that of thin ice (Tamura et al., 2007). Fast ice develops in the ASP region (Fraser et al., 2020; 2021). Therefore, the low SIC region extending offshore during winter in Fig. 10 is speculated to the underestimation due to the influence of fast ice. That is, the SIC of 70 (75)% threshold has no physical meaning. These show that the SIC from passive microwave radiometer is underestimated in thin ice (coastal polynya) and fast ice areas. So what is the point of such an ambiguous parameter-based estimate of the polynya area and the ice production? The estimation of SIC by the newer ASI algorithm used in this study may improve the SIC estimation in thin ice areas to some extent. However, a comparison of SIC using the ASI algorithm in the Ross Ice Shelf polynya and the Mertz Glacier polynya in Antarctica with the PSSM polynya map clearly shows that coastal polynyas are covered by thin ice, not open water, in winter (Kern et al. 2007). Moreover, the SIC is underestimated in these regions. It is reasonable to assume that new (thin) ice with 100% SIC covers the winter coastal polynyas. This is supported by the surface temperature from infrared satellite images, the thermal ice thickness estimated from heat

flux calculations using these images (e.g., Tamura et al., 2007), and the SAR images in this study. Based on these facts, the estimation of the winter coastal polynya area using SIC derived from passive microwave radiometer and sea-ice production there does not capture the reality and is meaningless. The heat insulation effect of sea ice decreases rapidly in the case of thin ice. Therefore, the more appropriate approach is to estimate the thermal thin ice thickness from brightness temperature observed by passive microwave radiometer, use it to determine the polynya area, and then estimate ice production from heat flux calculations (e.g., Tamura et al., 2008; Nihashi and Ohshima, 2015; Nihashi et al., 2017). Although these studies' estimates of polynya extent and production are cited (e.g., L. 123-128), the differences in the methods are not discussed at all.

This comment is helpful because it shows we have not been clear enough with our definition of 'open' polynya area in winter. We will more clearly define this in a revised paper. We agree that open ocean areas in the polynya during winter are quickly covered by thin ice formation. Note that we define the transition between 'winter' and 'summer' periods for the polynya based on whether the 'open' areas seen in the SAR are exhibiting ice formation or not. By 'open' polynya area in winter we mean where existing ice has advected away, leaving an area that is then the site of active new ice production (new frazil ice).

By comparing our SAR imagery with the ASI SIC data we found that the SIC data did a good job of representing the 'open' area during winter. For example the 21-23 September 2020 polynya event shown in Fig. 2 and video S1 can be clearly seen in Video S2 (which displays SIC data). Variations in the SAR can be seen captured by the SIC data throughout Video S2. It is clear from this comparison that the 'open' areas we find through the winter are not variations in fast ice coverage – opening and closing occurs in a manner consistent with polynya events, and is visible in the SAR when matching images are available. In a revised version of the paper we will also include a supplemental figure directly comparing SAR images with SIC data using a 70% threshold.

We also note that ASI's SIC data has been used in this way before in published work (Cheng et al., 2017; 2019) and we note that our mean annual estimate of ice production falls within the range of estimates by Tamura et al. (2008; 2016) and Nihashi et al. (2017).

In a revised version we will clarify the method used in the Tamura et al. and Nihashi et al. studies.

"Regarding the SAR data analysis in the first part of this study, the subsection title does indeed say "qualitative analysis" (L. 137; 335), but it is too qualitative. At L. 156-161, the authors describe the relationship between backscatter and ice (ocean) types. This would be generally true, but on what are these based? Quantitatively, which backscatter value corresponds to those surface types? There are no references at all. Furthermore, they did not compare with the SIC used in the second part of this study. At least, a comparison of SAR backscatter with surface temperature and ice thickness from MODIS infrared imagery, as shown in Nakata et al. (2019), will be needed."

We agree that more information should be provided on this. The differences between the ice types are not only quantitative differences in backscatter but

also textural. However we will include backscatter ranges, and an additional supplementary figure comparing the different ice types we identify that are important for our analysis. As mentioned above we will also include a supplementary figure comparing SAR imagery with SIC data (represented spatially).

We do not think that a comparison of SAR imagery with MODIS temperature and ice thickness data is necessary for qualitatively interpreting the imagery presented in this study, or would add significant information in the context of this study. MODIS data is not necessary to identify 'open' areas of ice production or polynya events, and would not aid in interpretation of other polynya dynamics (e.g. backfilling, obstruction).

"In the "qualitative analysis" described in subsection 4.1 starting at L. 335, the SAR images are only shown in Figs. 2 and 3, and the story is developed based mostly on video S1. However, many of the SAR images in this video are missing from the central part of ASP. This leads to difficulties in following the text. It is also extraordinary to say, "Instead, ice formed by the ASP often remains in the ASP study area for months (Video S1, Fig. 3)" (L. 605) from a discussion which is based solely on SAR images. Why can this be said only from temporally sporadic SAR images? In reality, it is reasonable to think that the area of the thin ice area does not change, and the new ice formed there is either thermodynamically growing or advected and deformed at the edge of the polynya. Therefore, dynamical and thermodynamic analyses with an ice motion are essential to justify the author's claim."

We make the claim "ice formed by the ASP often remains in the ASP study area for months" based on repeated and focused analysis of the SAR imagery. By visually analyzing the video and tracking changes in the ice it is evident that this is the case. Although temporal and spatial gaps in the video can be limiting, despite these gaps, by viewing the animated images it is possible to observe the flow and dynamics of the ice, including particular floes. While a dynamical and thermodynamical analysis of ice motion in the area would be valuable, we do not think it is within the scope of this study's goal to analyze the evolution of the polynya, or necessary to make this claim.

Best regards,

Dr Grant Macdonald, on behalf of all authors.