The Cryosphere Discussions

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Reply on RC1

Grant J. Macdonald et al.

Author comment on "Evolution of the dynamics, area, and ice production of the Amundsen Sea Polynya, Antarctica, 2016–2021" by Grant J. Macdonald et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2022-51-AC1, 2022

"I reviewed a previous version of this manuscript that was rejected by TC last year. The resubmitted paper has probably been revised based on the previous comments from the reviewers. However, unfortunately, the changes were minor. They are changes in wording and the deletion/increase of a few figures. At least for me, I felt that those were superficial modifications, and accordingly, I couldn't satisfy with them. Therefore, I recommend rejecting this paper mainly for the following reasons.

The points at issue:

Too qualitative analysis; lack of error analysis and science.

The unclear main focus of this study.

Misinterpretation of inappropriate satellite data."

Thank you for taking the time to review our paper, we respond to specific points below.

"This manuscript lacks quantitative analysis and also has no error analysis. This leads to a lack of science. Especially in SAR data analysis, this study only shows satellite images (without backscatter scale) and wind condition maps, and then they make stories. Fig. 8 of the previous manuscript was the only statistical analysis. However, the correlation was weak, and this figure has been deleted."

We disagree with the suggestion that qualitative analysis and visual interpretation of imagery constitutes a lack of science. Visual interpretation by experts and qualitative analysis are important tools in remote sensing where they enable findings often not possible with existing quantitative methods (i.e.

the dynamics and polynya events discussed in this paper). Qualitative analysis and visual interpretation of SAR imagery have been used in previous polynya studies (e.g. Hollands and Dierking, 2016; Dai et al., 2020). Inclusion of a backscatter scale is not standard in the literature for such images and including absolute values would not add to the qualitative analysis. Furthermore, the polynya area and ice production sections are indeed quantitative, and the polynya areas identified by the SIC data are assessed against an image of the 'open' polynya in SAR (Fig 2).

"It can be read that the main focus of this study seems to be on the biological production and chemical processes in the summer coastal polynya (complete ice-free ocean) and the accompanying carbon dioxide absorption. However, the biochemical analyses were not conducted in this study."

The main focus of the study is not biological production or chemical processes. We describe the aims of the study in the last paragraph of the introduction (lines 95-101). Biological/chemical processes are mentioned only as a motivation for better understanding polynyas.

"On the other hand, this manuscript estimates sea-ice production in a coastal polynya in winter (A small part may be an open water fraction, but it is mostly covered by frazil ice or thin solid ice). The purpose of estimating production is not clear; what is stated in L. 65 is insufficient. The dense water formed in winter coastal polynyas associated with the prominent ice production is an important source of AABW. This process of bottom water formation is thought to significantly impact the climate system through the transport of heat and substances such as carbon dioxide between the atmosphere and the deep ocean. However, this is not described at all in the manuscript."

Mention of the role of ice production in polynyas in AABW formation was removed from this version of the manuscript, upon suggestion of another reviewer, due this region not being an important contributor to AABW formation (e.g. Gordon, 2009). We could re-include mention of the role of ice production in AABW in general, while being clear it is not important in this specific case. Nevertheless, we emphasize that the goal of this paper is not to address bottom water formation and rather the study of the ice formation in polynyas. The importance of polynya ice production is discussed on lines 56-66, but in a revision we will also include mention of the importance of quantifying ice production for understanding the overall sea ice mass balance in the region.

"The use of SAR data is a challenging point in this study. However, as is clear from video S1, it has many temporal and spatial discontinuities. This suggests that it is not suitable for monitoring a coastal polynya whose variability is large."

We acknowledge that there are spatial and temporal discontinuities and this is a limitation (e.g. leads to gaps in qualitative analysis and is one of the barriers to an attempt at quantitative analysis) but disagree that this makes it not suitable for qualitative analysis. Processes such as polynya events and back-flow are observable despite these gaps, and indeed are *only* observable in winter with SAR.

"The authors defined surface conditions in SAR images as follows.

Open ocean: a low backscatter and appears dark

Older icepack: relatively high backscatter and appears bright and more granular

Recently-formed polynya produced ice: an intermediate backscatter

Frazil ice: distinct bands of varying brightness

However, this is very qualitative as it is affected by the SAR's incident angle. For example, in video S1, the open ocean may also appear white (e.g., 21-23 November 2016; 15-17 December 2016; 8-10 January 2017). These examples indicate the difficulty of conducting "quantitative" discussions of sea-ice and open water areas from SAR images."

We agree and acknowledge that our analysis is qualitative here. We disagree, however, that this discounts the merit of our study. The differences between these key features is generally clear in the context of the images. It was an oversight for us not to mention that open ocean may also have high backscatter during windy conditions – as it the case in the example dates given here. We will mention this in a revision. However, it is clear from the context of the images that these bright areas are open ocean and not sea ice, and therefore it did not lead to mis-interpretations.

"The use of such sparse and unquantifiable data leads to misinterpretation. The authors state that "approximately all of the ice produced between 30 April and 4 November by the main polynya is contained within the red outline on 4 November in Fig. 4" from the SAR images in Video S1 and Fig. 4 (L. 403-405). This is a lack of science to tell this from SAR data alone. It is more natural to assume that the sea ice will grow both thermodynamically and dynamically during this long period of 6-months, resulting in a backscatter similar to that of one-year ice. In any case, this cannot be suggested solely from the SAR images."

We do not agree this is a mis-interpretation. This was determined by carefully qualitatively analyzing the video and imagery. It is clear from the image presented in Fig. 4 that the highlighted area of ice has a distinct backscatter from the pack ice in the region, and it is clear from carefully analyzing the video and imagery that this is ice produced by the polynya during that season. We agree that the ice would continue to grow dynamically and thermodynamically during this period, but that does not contradict that it was initially formed in the polynya.

This result is not central to the study and can be removed if the editor agrees that it is problematic.

"The definition of a winter coastal polynya area based on AMSR2 sea-ice concentration (SIC) is questionable. Firstly, this study ignores heat loss and sea-ice production in thin

ice areas, the dominant type of sea-ice in winter coastal polynyas. Secondly, an area with SIC <70% was defined as a polynya area, but SIC by the ASI algorithm underestimates SIC in thin ice areas. A similar analysis had to be performed using SIC with other AMSR2 algorithms, and error analysis also had to be performed.

*In a previous review, I pointed out the definition of a coastal polynya area. As in the previous manuscript, this manuscript also treats the area where the SIC by AMSR2 is <70% as the polynya (open water) area. The previous manuscript was based on studies of the comparison between a coastal polynya area from the polynya signature simulation method (PSSM) by Markus and Burns (1995) and SIC (Parmiggiani, 2006; Morelli & Parmiggiani, 2013; Preußer et al., 2015). The new manuscript added a comparison with SAR images (Figs. 2b-g). The black low backscatter area (open ocean) in Fig. 2b corresponds to the low SIC area (SIC <70%) in Fig. 2e. Since this is not a SIC map, I do not know the details, but the correspondences between the open ocean and the low SIC (not open ocean) areas seem strange. On the other hand, Figs 2c-d shows a bright band-like feature, which is considered to be covered with frazil ice. Since no dark areas can be seen, it is assumed that this area is mostly covered with sea ice. In other words, the SIC must be close to 100%. However, the AMSR2 map shows a low SIC of <70%. T*he two areas certainly coincide, but they are not consistent in terms of SIC*"*

On lines 170-173, during winter, we state "*Frazil ice, that may form when a polynya opens up and the open ocean begins to freeze, forms in distinct bands of varying brightness (Fig. 2c-d). Note that what we refer to as 'open' polynya area during the winter will typically be filled with thin, newly-forming frazil ice."*

On lines 187-191 we state "*Following other studies (e.g. Dai et al., 2020) during the winter we also use the term 'open polynya' for areas that we include in the polynya, where an opening has been created and new ice production is taking place. However, during the winter we expect thin ice to immediately begin forming when an opening is created, and thus we note the area is not truly 'open' ocean."*

Therefore, Fig 2 shows an expanding 'open' polynya during a polynya event and the corresponding identified 'open' polynya using 70% SIC as a threshold. The figure shows good agreement (as does comparing Video S1 and S2) for other such events. This definition of 'open' polynya during winter (i.e. when a polynya event takes place, opening the ocean, where thin/frazil ice ~immediately starts forming due to cold temperatures) is consistent with that in the literature (e.g. WMO, 1970; Nihashi and Ohshima, 2015; Cheng et al., 2017; 2019; Dai et al., 2020; Nakata et al., 2021). In fact Nakata et al, 2021 recently mapped major polynyas around Antarctica during winter specifically by identifying frazil ice areas (We will add reference to this paper in a revision). And the WMO (1970), quoted within Nihashi and Ohshima (2015), states "*Polynyas are defined as ''any non-linear shaped opening enclosed within sea ice, and may contain brash ice and/or may be covered with new ice, nilas, or young ice'' (WMO 1970)."* Dai et al., 2020 measure polynya area by manually mapping open/frazil-covered areas in Sentinel-1 akin to that shown in Fig. 2. In summary: we already state that 'open' polynyas include newly-forming ice, this definition is consistent with previous studies, and comparison of SAR and our SIC data show that the SIC data (with 70% threshold) effectively identifies 'open' winter polynya.

If it would be clearer to use the term 'active' polynya rather than 'open', we can make that change. We could also draw on a boundary of the interpreted 'open/active' polynya on the SAR images in Fig 2 if it is not clear enough from the image alone. We will also review the text in general for clarity regarding the definition of an open/active polynya during winter.

We suggest that comparing the SIC 70% threshold results to an actual SAR image from the same day is a better form of validation than comparing to another SIC product.

"Furthermore, even though the area is considered to be covered by ~100% frazil (thin) ice, the authors did not consider the presence of sea ice at all in their estimate of sea-ice production and assumed an ice-free (open) ocean (eq. 1-10)."

The area will be open ocean at the initial point of ice production when the old ice moves away as part of the polynya event, exposing the ocean, where the new ice forms. We acknowledge this is an imperfect modelled estimate.

"There is an area of intermediate backscatter below (west of) the areas shown as low backscatter area (open ocean, Fig 2b) and the area shown as the band-like feature (frazil ice, Figs. 2c-d). These areas are considered to be "the recently-formed polynya produced ice" as described by the authors. This area is considered to be covered by thin sea ice with ~100% SIC. The sea-ice production in this area is expected to be significant. Sea ice acts as a heat insulator between the atmosphere and the ocean, but its effect decreases rapidly as the ice thickness decreases. The authors had ignored the sea-ice production in thin ice areas."

We agree that ice growth will take place in these areas but the study focuses on ice production by the 'open' polynya i.e. during polynya events. We will review the text for clarity on this.

"SIC estimated from brightness temperatures observed by satellite passive microwave radiometer is underestimated in areas covered with new and thin ice areas, such as coastal polynya (Cavalieri et al., 1994). The authors stated an error in the ASI SIC algorithm but ignored the effects of thin ice (L. 204). As described in the previous review comment, 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)."

We acknowledge on lines 170-173 and 187-191 that newly-forming thin ice exists in an 'open polynya' (i.e. in a polynya event) in winter. We show in Fig. 2 that the ASI SIC data with a 70% threshold effectively captures these 'open' areas, and this approach was also followed by Cheng et al., 2017; 2019) in the Ross Sea. As mentioned above, although 'open polynya' has been used elsewhere in the literature we could change this term to 'active polynya' if it would be clearer.

"Moreover, the SIC is underestimated in these regions. The authors should show an error analysis for this. In addition to ASI, NT2 and Bootstrap are other major algorithms for estimating SIC. The analysis had to be done using these SICs as well. Their spatial resolution (about 12 km) is coarser than that by ASI, but it is sufficient to resolve the Amundsen polynya."

As mentioned above, we suggest that comparing the SIC result to actual image of the polynya on the same day is a better form of checking and validating the method than comparing to another, low-resolution SIC product.

Regarding the point in the opening paragraph about the study's focus being unclear, we will review the introduction for clarity. Presently we do attempt to explicitly lay out the focus on lines 90-101, including specific objectives on lines 95-101.

Best regards,

Dr Grant Macdonald, on behalf of all authors.

Additional References

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