We would like to thank Ethan Campbell for his nice words about our work and the interesting and useful comments. In order to follow more easily the discussion, his points are in italics below, our response in plain text.

I want to thank the authors for submitting this fascinating work to Climate of the Past. The journal allows members of the broader scientific community to comment on preprints during the open discussion period. I thought I'd use the opportunity to provide a few brief thoughts, which are not intended to be an exhaustive review. As someone with a close interest in the Weddell polynya phenomenon (e.g. Campbell et al. 2019), I found this study to be particularly exciting. The techniques used by the authors to identify the fingerprints of past polynyas in ice core records of surface mass balance (among other data) seem well-motivated and promising. Without commenting further on the technical aspects of the study, I wanted to share five ideas/suggestions:

1. Meier et al. (2013) analyze recovered Nimbus I satellite imagery and highlight the possibility of a large Weddell Sea opening in 1964 on the basis of a polynya-like feature found in their imagery (see their Fig. 5). It would seem that your reconstructions (Fig.6b) mostly exclude the possibility of a major, long-lasting polynya in that year. It would be interesting to discuss the relevance of your analysis to their findings.

We are sorry that we missed the reference to the study of Meier et al. (2013) and their results will be discussed in the revised version of the manuscript. Meier et al. (2013) present indications of the presence of reduced ice concentration in the region of the formation of the Weddell polynya in September 1964 but, because of the small number of available observations, they state that 'However, it is not clear if there was a polynya at or near the time of the image or just an indication of leads and clouds.' Our methodology is designed to identify large open ocean polynyas, as in 1974-1976. Short events have a too small imprint to distinguish them in ice core records. We cannot conclude from our results if a polynya was present or not in September 1964, but our reconstruction indeed suggests that no event similar to the opening in 1974-1976 occurred at that time.

2. Broecker et al. (1999) speculate that deep convection in Antarctic open-ocean polynyas must have supplied a greater amount of AABW during the Little Ice Age(~1350-1880) in order to meet present-day PO4 and 14C tracer budgets, with cessation of most open-ocean convection occurring during the post-Little Ice Age transition(possibly 1880-1945, or ongoing). It should be noted that aspects of this interpretation have since been challenged, e.g. by Orsi et al. (2001), who find bottom water ventilation rates from CFCs that seem to agree with those inferred from 14C distributions. There are also some intricacies involving differences in bottom water definitions. Nonetheless, is it possible that your reconstruction could shed some light on the conjecture raised by Broecker and colleagues, as well as their interesting suggestion that"ventilation of the deep Southern Ocean is episodic rather than steady"?*

The potential impact of centennial-scale changes in open ocean polynya formation on deep water formation is a strong motivation for our work, as discussed in the introduction. Nevertheless, our results do not address specifically this point at this stage. We did not want to speculate too much on this subject in the submitted

manuscript as we had not much specific information to add and thus prefer to leave this for subsequent studies. On a more general point, the magnitude of the changes in ocean circulation over the past millennium as well as their impact are very uncertain. For instance, in a previous study (Goosse 2018), the transport of anomalies by the mean circulation in the Southern Ocean has been shown to explain the timing of some warm events before the LIA (based on mechanisms similar to the ones proposed for the more recent past, see Marshall et al., 2015 or Armour et al. 2016) but I was not able to identify a contribution of changes in the circulation.

3. To the point in Lines 128-130 that "no high-resolution ocean sediment core that might provide a direct record of polynya activity is available": This unfortunately seems to be the case, as the most promising cores from ODP Sites 689/690 on Maud Rise have rather condensed Pleistocene sections due to low accumulation rates, and are possibly too dry at this point to yield useful samples. However, I anticipate that this study may well motivate future efforts to obtain new polynya proxy records, such as ocean sediment cores from sites with higher accumulation rates at Maud Rise or elsewhere. (I have been thinking about this, as have others!). I wonder if you could comment on how your method and resultant reconstruction of past polynya events from ice core records could complement or inform a similar effort using ocean sediment core records, which would likely cover millennial and longer scales, rather than the decadal-to-centennial scales examined in this study.

That would be great if our study could motivate the collection of new records allowing to refine the reconstructions of past polynya activity. We can anticipate significant practical problems, related to the recovery of a high-resolution oceanic core in the region, its interpretation, the maybe small overlap with the ice cores sensitive to open ocean polynya formation (some of them cover only a few centuries), etc. However, there is no fundamental problem to combine different records using the method we have applied. This is a very interesting perspective, in particular as the ocean sediment core records could constrain the low frequency variations that may be difficult to identify from the ice core records and we will mention it in the revised version of our manuscript.

4. I would be interested in seeing Lines 463-466 expanded to discuss alternative ice core chemical proxies in slightly more detail. Past work (e.g. Criscitiello et al. 2013) has attempted to reconstruct coastal polynya variability using sea salt aerosol proxies and is very relevant here. It might be useful to be specific as to which proxies might yield additional constraints on the open-ocean polynya reconstruction.

The intention in the submitted manuscript was not to go in the details on this point. This is the reason why we just cite review studies focusing on the reconstruction of the sea ice (or of its absence in the case of a polynya). Without a deeper investigation, it is hard to guess which proxy will provide the largest constraint but sodium and chlorine content in ice cores (sea salt) are very good candidates. The source of sea salt aerosol to the polar atmosphere strongly depends on the condition at ocean surface, specifically the presence of sea ice. The formation of an open ocean polynya in winter should thus have a large impact on the sea salt transferred to the atmosphere in the Weddell Sea. This signal can then be transported to the continent by the winds and recorded in ice cores. Although biological activity in the polynya itself may be limited in

winter, the formation of the open ocean polynya can have an impact of the vertical structure of the water column, on light availability, on the nutrient input at surface and thus on biological production later in the season (e.g., von Berg et al. 2020). This might also be recorded in ice cores, for instance in their Methanesulfonic acid content. Those proxies have been used to reconstruct coastal polynyas (e.g., Rhodes et al. 2009, Criscitiello et al. 2013; Mezgec et al. 2018). We are not aware of any study analyzing the link between open ocean polynya activity and those chemical records, so this deserves more investigation. However, as suggested, this point will be developed in the revised version of the manuscript.

5. Resplandy et al. (2018) in Nature, cited on Line 79, has been retracted; the re-published version in Scientific Reports is Resplandy et al. (2019).

Thanks a lot for pointing this. We will cite the updated version in the revised version of the manuscript.

References:

Armour, K.C., Marshall, J., Scott; J.R., Donohoe, A., Newsom, E.R., Southern Ocean warming delayed by circumpolar upwelling and equatorward transport. Nat. Goes., DOI: 10.1038/NGEO2731, 2016.

Broecker, W. S., Sutherland, S., and Peng, T.-H.: A possible 20th-century slowdown of Southern Ocean deep water formation. Science, 286, 1132–1135,doi:10.1126/science.286.5442.1132, 1999.

Campbell, E. C., Wilson, E. A., Moore, G. W. K., Riser, S. C., Brayton, C. E., Mazloff, M. R.,and Talley, L. D.: Antarctic offshore polynyas linked to Southern Hemisphere climate anomalies. Nature, 570, 319–325, doi:10.1038/s41586-019-1294-0, 2019.

Criscitiello, A. S., Das, S. B., Evans, M. J., Frey, K. E., Conway, H., Joughin, I., Medley, B., and Steig, E. J.: Ice sheet record of recent sea-ice behavior and polynya variability in the Amundsen Sea, West Antarctica. J. Geophys. Res. Ocean, 118, 118–130,doi:10.1029/2012JC008077, 2013.

Goosse, H., 2017: Reconstructed and simulated temperature asymmetry between continents in both hemispheres over the last centuries. Clim. Dyn. 48, 1483–1501, doi:10.1007/s00382-016-3154-z.

Levine, J. G., Yang, X., Jones, A. E., Wolff, E. W.: Sea salt as an ice core proxy for past sea ice extent: A process based model study, J. Geophys. Res. Atmos., 119, 5737–5756, doi:10.1002/2013JD020925, 2014.

Marshall, J., Scott, J.R., Armour, K.C., Campin, J.-M., Kelley, M., Romanou, A.: The ocean's role in the transient response of climate to abrupt greenhouse gas forcing. Clim. Dyn. 4, 2287-2299, 2015

Meier, W. N., Gallaher, D., and Campbell, G. G.: New estimates of Arctic and Antarctic sea ice extent during September 1964 from recovered Nimbus I satellite imagery. Cryosph., 7, 699–705, doi:10.5194/tc-7-699-2013, 2013.

Mezgec, K., Stenni, B., Crosta, X., Masson-Delmotte, V., Baroni, C., Braida, M., Ciardini, V., Colizza, E., Melis, R., Salvatore, M.C., Severi M., Scarchilli C., Traversi R., Udisti R. and Frezzotti M.: Holocene sea ice variability driven by wind and polynya efficiency in the Ross Sea. Nat. Commun., 8, 1334, 2017.

Orsi, A. H., Jacobs, S. S., Gordon, A. L., and Visbeck, M.: Cooling and ventilating the abyssal ocean. Geophys. Res. Lett., 28, 2923–2926, doi:10.1029/2001GL012830, 2001.

Rhodes, R.H., Bertler, N.A.N., Baker, J.A., Sneed, S.B., Oerter, H., Arrigo, K.R.; Sea ice variability and primary productivity in the Ross Sea, Antarctica, from methylsulphonate snow record. Geophys. Res. Lett., 36, L10704. doi:10.1029/2009GL037311, 2009

Rhodes, R. H., Yang, X., Wolff, E.W.: Sea ice versus storms: What controls sea salt in Arctic ice cores? Geophysical Research Letters, 45, 5572–5580. https://doi.org/10.1029/2018GL077403, 2018.

Resplandy, L., and Coauthors : Quantification of ocean heat uptake from changes in atmospheric O_2 and CO_2 composition. Nature, 563, 105–108, doi:10.1038/s41586-018-0651-8, 2018.

– –, and Coauthors : Quantification of ocean heat uptake from changes in atmospheric O_2 and CO_2 composition. Sci. Rep., 9, 20244, doi:10.1038/s41598-019-56490-z, 2019.

von Berg, L., Prend, C. J., Campbell, E. C., Mazloff, M. R., Talley, L. D., and Gille, S. T.: Weddell Sea phytoplankton blooms modulated by sea ice variability and polynya formation. Geophysical Research Letters, 47, e2020GL087954. https://doi.org/10.1029/2020GL087954, 2020