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Interactive comment on "Multidecadal Preconditioning of the Maud Rise Polynya Region" *by* René M. van Westen and Henk A. Dijkstra

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Point-by-point reply to reviewer #2

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We thank the reviewer for his/her careful reading and for the useful comments on the manuscript.

Major comments:

1. *What is the Southern Ocean Mode? There are very few modeling studies that even consider it. Do the authors consider it to be a different mode from the Southern Annular Mode (SAM)? However, one of the definitions of SAM index is the difference between normalized zonally mean sea level pressure between 40S and 65S (Gong and Wang 1999). (SAMindex = P*40S – P*65S) whose Atlantic sector encompasses the region used in the definition of SOM. The authors do not provide an explanation as to why the SOM index is an independent mode. The Southern Annular Mode could in fact influence the Temperature anomaly over 0-50W;35-50S. It would be very helpful if the authors can show that the SOM index is different from the SAM index. It is really not clear why this is a better metric or how this region behaves as an independent influence on the preconditioning of the polynyas over Maud Rise.*

   Author's reply:
   To provide more information on the relation between the SOM and SAM, we have

already performed additional analysis. First, we analysed the SOM using the stand-alone POP simulation which was first used to detect the SOM (Le Bars et al. 2016) using a Principal Component Analysis (PCA) of the upper ocean temperature fields in the Southern Ocean. A large-scale pattern of variability is found then with a period of about 40 – 50 years. In the stand-alone POP model, the associated PC displays the same multidecadal variability as the SOM index in Le Bars et al. (2016). This multidecadal variability is not related to any atmospheric variability since the atmospheric forcing is seasonally varying in the stand-alone POP.

Secondly, the same PCA (as above) is done for the CESM (fully coupled climate model). The first principal component displays a 25-year period and this period is significant against red noise in the CESM. The SOM index time series contains much more noise compared to the first principal component. The noise in the SOM index is likely related to atmospheric variability (which is absent in the stand-alone POP). Therefore, we do not use the SOM index in the revision anymore but the first principal component time series of the PCA.

Finally, we determined the SAM index in the stand-alone POP and in the CESM. The SAM index is constant in the stand-alone POP. For the CESM, the SAM index displays inter-annual variability over the 101-year period. In both the stand-alone POP and CESM results, we find no relation between the SOM and SAM.

Changes in manuscript:
We will include a new section in the revision: The Southern Ocean Mode. In this section, the PCA analysis is described and we motivate why the SOM is different from the SAM. In the revision, we will use the first principal component of the PCA to measure the SOM instead of the SOM index. All figures and results will be changed accordingly.

2. *The authors do not present a robust justification for using only the SOM and not looking at any of the important factors that play a role in preconditioning*

such as the structure and strength of the Weddell gyre (Cheon et al. 2015) , the SAM index (Gordon et al. 2007), or the presence of stratified Taylor columns over Maud Rise (de Steur et al. 2007; Alverson and Owens 1996). Previous literature (Hirabara et al. 2012) suggests that the preconditioning and formation mechanism of these MRPs are related to several contributing factors that involve the interaction of large- and smallscale ocean/atmospheric circulation. The authors here do not provide a clear physical connection on how the SOM can in turn influence these other contributing factors for polynya formation. The lack of a physical mechanism clearly linking the SOM to the MRPs is a major weakness in this publication.

Author's reply:
We have analysed the SAM index in CESM, but find no connection with the SOM (see also Major comment 1). We determined the zonal mass transport at 30°W as a measure for the Weddell gyre strength. The Weddell gyre strength also varies with the same 25-year period as the SOM. We found stratified Taylor column over Maud Rise in the CESM which are important for preconditioning the Maud Rise region. Changes in the surface salinity can also contribute to preconditioning. We already have analysed changes in the surface salinity but the surface is freshening prior to Polynya formation.

Changes in manuscript:
We will include the SAM index time series in the new section 'The Southern Ocean Mode', as well as the Weddell Gyre analysis. We will include the analysis of the surface salinity and the Taylor columns over Maud Rise. Preconditioning by surface salinity, Taylor columns and the SAM index will be discussed in section 'Preconditioning of the Polynya region'. The results and parts of the text will be changed accordingly.

3. *The loosely connected interpretation of figures 5,6 and 7 suggests that particles*

released over the MRP box and backtracked for 8 years end up in specific regions in the Weddell gyre that are correlated to parts of the SOM region. However, correlation does not imply causation.

Author's reply:
We have updated the lag-correlations patterns since we do not use the SOM index time series in the revision. The lag-correlation patterns overlap with the regions of where the particles end up, indicating that positive subsurface anomalies at that time propagate towards the Polynya region.

Changes in manuscript:
We will rewrite this paragraph of the manuscript and will also include lag-correlations patterns (cf. Major comment 4) to demonstrate the propagation of positive subsurface heat anomalies along the Weddell Gyre. The text, results and figures will be changed accordingly.

4. *If the subsurface OHC anomalies from the SOM region propagate along the Weddell gyre to the MRP box in ten years, one should be able to see a pattern in the correlation between SOM and H1000 in which the SOM leads H1000 in steps of 12-24 months (similar to figure 5d but in steps where SOM leads H1000 in 24, 48, 72, 96 months). It would help readers to see the intermediate steps of SOM leading H1000 by 12-24 months between figures 5c and 5d in which the propagation should be evident if such connections exist.*

   Author's reply:
   Suggestion followed.

   Changes in manuscript:
   We will include lag-correlation patterns in the revision. Note that we will not use the SOM index anymore for the lag-correlations. The results and figures will be changed accordingly.

Minor comments:

1. *The mapping projection in figure 5 is not consistent with figures 6-7. Please be consistent with the mapping projections.*

   Author's reply:
   Suggestion followed.

   Changes in manuscript:
   All the relevant figures are remapped and will be consistent.

2. *The authors mention 3 MRP events observed in 1973-1977,1994 and 2016-2017 to suggest a periodicity of 20 years between MRP events. They did not include the MRP event of 1980 (Comiso and Gordon 1987). The observations do not suggest a periodicity of 20 years. The polynyas of the late-70s were extremely large Weddell Sea Polynyas that begin over Maud Rise and spread westward into the Weddell Sea and have not been observed since.*

   Author's reply:
   Thanks for pointing this out.

   Changes in manuscript:
   The text will be rewritten accordingly.