Response to 2nd Review Comments
for

"The response of sea ice and high salinity shelf water in the Ross Ice Shelf Polynya to cyclonic atmosphere circulations"

Xiaoqiao Wang, Zhaoru Zhang, Michael S. Dinniman, Petteri Uotila, Xichen Li, Meng Zhou

Note: Reviewers' comments are highlighted by blue color; authors' responses are in black color. Revisions in the revised manuscript are highlighted by blue color.

Reviewer comments:

Anonymous Referee #1:

The authors have addressed most of my comments very nicely. In general, I am satisfied with the authors' efforts. Her are only a few minor comments.

We thank the reviewer for his/her efforts in reviewing this manuscript and providing useful and helpful comments that further improved our manuscript.

1. With Figures R1 and R2, at ~177W, there is a large region with thick sea ice and low sea ice concentration, which extends to the north. Without the thick ice covered, which can inhibit the ocean from losing heat to the atmosphere, there should be an active heat exchange and sea ice production. However, it is not reflected in Figure 5. Moreover, if we identify the polynya by ice thickness (e.g., <20 cm, Nihashi et al., 2017), or sea ice concentration (e.g., < 0.7, Ding et al., 2020), I think this region will be considered as a part of RSP. But when the polynya is identified by SIP, the extent of the polynya obviously does not include this region. So the inconsistency between the SIP and ice thickness and sea ice concentration may affect the calculation of the polynya area. So, I think it's necessary to explain why low SIP occurs in the thin ice regions.

Reference

Ding, Y., Cheng, X., Li, X., Shokr, M., Yuan, J., Yang, Q., & Hui, F. (2020). Specific relationship between the surface air temperature and the area of the Terra Nova Bay polynya, Antarctica. Advances in Atmospheric Sciences, 37(5), 532–544. https://doi.org/10.1007/s00376-020-9146-2
Nihashi, S., Ohshima, K. I., & Tamura, T. (2017). Sea-Ice Production in Antarctic Coastal Polynyas Estimated From AMSR2 Data and Its Validation Using AMSR-E and SSM/I-SSMIS Data. Ieee Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10(9), 3912–3922. https://doi.org/10.1109/Jstars.2017.2731995

Figures R1 and R2 are the snapshots of sea ice thickness and sea ice concentration patterns during the first synoptic-scale cyclone event, which was affected significantly by the synoptic process. However, the identification of polynyas is usually determined by the average value from April to October (Ding et al., 2020) or June to September (Kern., 2009). By examining the spatial distribution of multiyear averaged sea ice concentration and sea ice thickness in our study, it actually shows consistent features with sea ice production, i.e., thick ice and low production.

Reference:

Kern, S., 2009: Wintertime Antarctic coastal polynya area: 1992–2008. Geophys. Res. Lett., 36, L14501, https://doi.org/10. 1029/2009GL038062.

2. Line 394–395: considering the large P-value here, the correlation between the meridional wind speed and the HSSW export 12-hours later could be described as "significant but also weak".

Following the reviewer's suggestion, the original sentence "For S3 on the other hand, there was a positive significant correlation between the meridional wind speed and the HSSW export 12-hours later (R=0.53, P=0.042)." has been revised to "For S3 on the other hand, there was a significant but weak positive correlation between the meridional wind speed and the HSSW export 12-hours later (R=0.53, P=0.042)." (Lines 402–404 in the revised version).

3. The red lines of sections and yellow boxes in Figure 15 are difficult to see. Maybe its color should be changed.

The red lines and yellow boxes have been modified to more visible colors in the revised Figure 15.

Anonymous Referee #3:

Here are some special comments (line number refer to the version with tracked changes):

1) Line 148 "AMSR-E SIP", could you give some assessments on the potential errors for this product? Is it sensitive to the synoptic process, e.g., the increased cloud cover and humidity during the cyclone?

As mentioned in the original manuscript, the derived AMSR-E SIP is estimated based on a simplified heat flux calculation that ignores the oceanic heat flux for sea-ice freezing/melting process, and therefore the contribution of oceanic heat flux could not be presented by this product. Meanwhile, the AMSR-E SIP product does not discriminate the active-frazil area for Antarctic coastal polynyas, which could result in an underestimation of sea ice production for frazil-dominant polynyas (Nakata et al., 2021). On the AMSR-E SIP website (http://www.lowtem.hokudai.ac.jp/wwwod/polar-seaflux/), the estimated sea ice production dataset (the data used in this study) is available as monthly results, and the effects of synoptic processes on ice production could not be well captured based on the monthly outputs. The increased cloud cover during the cyclones could induce the overestimated ice thickness (Tamura et al., 2007), as cloudiness is used in the heat flux calculation (Nihashi and Ohshima, 2015). The thicker ice thickness suggests smaller heat loss, which finally results in lower ice production based on the AMSR-E dataset. The increased humidity gradients could reduce ice production and sea ice concentration by increasing turbulent fluxes (Taylor et al., 2018). The discussions of potential errors of the AMSR-E SIP production are added as "In addition, the AMSR-E SIP product does not discriminate the active-frazil area for Antarctic coastal polynyas, which could result in an underestimation of sea ice production for frazil-dominant polynyas (Nakata et al., 2021)." in Lines 182–184 of the revised version.

References:
Nakata, K., Ohshima, K. I., & Nihashi, S. (2021). Mapping of active frazil for Antarctic coastal polynyas, with an estimation of sea-ice production. Geophysical Research Letters, 48, e2020GL091353. https://doi.org/10.1029/2020GL091353

Nihashi, S. and Ohshima, K. I. (2015). Circumpolar Mapping of Antarctic Coastal Polynyas and Landfast Sea Ice: Relationship and Variability, J. Clim., 28, 3650–3670, https://doi.org/10.1175/JCLI-D-14-00369.1.

Tamura, T., Ohshima, K. I., Markus, T., Cavalieri, D. J., Nihashi, S., & Hirasawa, N. (2007). Estimation of Thin Ice Thickness and Detection of Fast Ice from SSM/I Data in the Antarctic Ocean, Journal of Atmospheric and Oceanic Technology, 24(10), 1757-1772.

Taylor, P.C., Hegyi, B.M., Boeke, R.C., Boisvert, L.N. (2018). On the Increasing Importance of Air-Sea Exchanges in a Thawing Arctic: A Review. Atmosphere, 9, 41. https://doi.org/10.3390/atmos9020041.

2) Line 153 "ERA-Interim reanalysis" could you explain why don't you use the updated version of ERA reanalysis data (ERA-5), that has a higher resolution.

The primary reason for using ERA-Interim reanalysis products is that the model was developed early, and long-term simulations were conducted before the ERA5 product came out. In this study, we picked up key periods within the long-term simulation under the influence of synoptic- or mesoscale cyclones, and re-ran the model to generate 6-hourly output (the original output as 5-day-average) to study the impacts of cyclones with short lifetime. For consistency between the atmospheric forcings for the restart fields and model re-run, we used ERA-Interim product for the re-run as well. In addition, we used to examine the sea level pressure (SLP) fields during the passage of cyclones for other Southern Ocean regions for both ERA-Interim and ERA5, such as the Prydz Bay in our previous study, and found the SLP patterns are very similar between the two products, and there are also strong correlations between wind speed from the two datasets. Combining this fact and the consideration for model consistency as mentioned above, we maintained using ERA-Interim as the forcing fields for the model simulation during cyclone events.

3) Line 158 "between wind speed from ERA-Interim and observations": Where did the observation data come from?

The observational data come from the Reference Antarctic Data for Environmental Research (READER) project website (http://legacy.bas.ac.uk/met/ READER), which has been mentioned in the original manuscript "The wind speed data are available at the Reference Antarctic Data for Environmental Research (READER) project website.". To make this clear, this sentence has been revised to "The observed wind speed data are available at the Reference Antarctic Data for Environmental Research (READER) project website (http://legacy.bas.ac.uk/met/READER)." (Lines 154–156 in the revised version).

4) Line 184 "Correlation coefficients between the modeled and observed sea ice concentration": Absolute and relative deviations are also very important.

As the reviewer suggested, we calculated the absolute and relative deviations for the modeled sea ice concentration in 2005 and 2014. The absolute deviations are -0.31 and -0.29 for 2005 and 2014 respectively. The relative deviations for 2005 and 2014 are respectively 36.7% and 34.6%. Generally, our study focuses on the temporal variation of sea ice concentration, i.e., the changes before and after these cyclones, so the correlation coefficients are much more important compared with these deviations. Still in the revised text, we added the information of absolute deviations of modeled ice concentration (Lines 189–190 in the revised version).

5) Line 216 "The cyclones were categorized into two types depending on their horizontal scale": What are the essential differences between these two kinds of cyclones the horizontal size? How to judge these cyclone processes does not have the superimposed contributions from the katabatic wind?

The synoptic-scale weather systems typically have a horizontal length scale in the range of 1000–6000 km and a lifetime of between one day and a week. The mesoscale cyclones are relatively short-lived, sub-synoptic-scale low-pressure systems, and their limited horizontal scale of less than 1000 km and lifecycle of normally under 24 h (King and Turner., 1997). Therefore, the threshold in our study is 1000 km to identify these two types of cyclones, following Uotila et al. (2013). The synoptic-scale depressions form mainly on stronger horizontal temperature gradients (baroclinic zones) in the troposphere and grow through baroclinic instability. Strong gradients of sea surface temperature are also responsible for the establishment or reinforcement of atmospheric baroclinic zones within which synoptic-scale cyclone can develop. However, many atmospheric thermal gradients near ocean fronts will be relatively shallow features and most of the vortices developing there will be mesocyclones rather than major synoptic systems. Turner and Thomas (1994) also demonstrated that mesocyclones are predominantly an oceanic phenomenon. The mesocyclones are usually the cold air vortices forming to the south of the main polar front and develop in outbreaks of polar air well removed from pre-existing frontal cloud bands. Such information is added in Lines 222–224 of the revised version.

There are two definitions for the katabatic wind. The narrow definition is the air flows generated by the combined effects of gravitational force and pressure gradient (due to radiative cooling of air over glacier and thermal gradient in air above the glacier and above sea) force near the Antarctic coast, which is a local feature. The wide definition is "downslope air flow", which includes the effect of cyclones (Parish and Cassano, 2003). The forcing fields used in our study come from the ERA-Interim reanalysis products which assimilated data from several Antarctic meteorological stations, and should include some information of local katabatic wind. However, the coarse spatial resolution of these products cannot fully represent the small-scale local katabatic wind. If we consider the wide definition of katabatic wind, it is largely affected by the interactions of cyclones with the geography, and the cyclones can be well captured in the reanalysis products.

References:

King, J., & Turner, J. (1997). Antarctic Meteorology and Climatology (Cambridge Atmospheric and Space Science Series). Cambridge: Cambridge University Press. doi:10.1017/CBO9780511524967.

Parish, T. and Cassano, J. (2003). The Role of Katabatic Winds on the Antarctic Surface Wind Regime, Mon. Weather Rev., 131, 317–333.

Turner, J. and Thomas, J.P. (1994), Summer-season mesoscale cyclones in the bellingshausen-weddell region of the antarctic and links with the synoptic-scale environment. Int. J. Climatol., 14: 871-894. https://doi.org/10.1002/joc.3370140805.

Uotila, P., Vihma, T., and Tsukernik, M. (2013). Close interactions between the Antarctic cyclone budget and large-scale atmospheric circulation, Geophys. Res. Lett., 40, 3237–3241, https://doi.org/10.1002/grl.50560.

6) Line 268: "indicate complete cyclone trajectories of selected cases": Could you show the time series of the trajectories in the illustration?

Following the reviewer's suggestion, the trajectories in Figure 3 have been modified by adding the start and end positions (indicated by different markers) to present the change in positions over time, The detailed information has been added as "… the pentacles indicate the starting positions and the diamonds present the ending positions." (Lines 276–277 in the revised version).

7) Line 398: "such as ice shelf circulations": What do you mean the ice shelf circulations here?

Sorry for the confusion. The ice shelf circulation mainly refers to the circulations of ice shelf basal melting water, so this sentence has been modified to "other factors (such as the circulations of ice shelf basal melting water) could regulate the HSSW exports significantly." (Lines 407–408 in the revised version).

8) "4 Conclusions": Differences of impacts on productions of sea ice and high-salt shelf water between synoptic- and meso-scale cyclones are still not clear. In the conclusions, you should make it more distinct, and highlight it.

Thanks for the reviewer's suggestion, the original statement "When synoptic-scale cyclones prevailed over this region, the entire RISP was dominated by strong offshore winds, which resulted in increased

SIP rates. During the passage of the mesoscale cyclone, SIP increased rapidly over the western side of RISP but decreased over the eastern side of RISP, due to changes in the offshore winds associated with the cyclonic wind field.” have been revised to “When synoptic-scale cyclones with spatial size over 1000 km prevailed over this region, the entire RISP was dominated by strong offshore winds, which resulted in increased SIP rates in the entire RISP. While during the passage of mesoscale cyclones with radii less than 1000 km, SIP increased rapidly over the western side of RISP but decreased over the eastern side of RISP, due to changes in the offshore winds associated with the cyclonic wind field.”, in order to emphasize the difference impacts of the two cyclones types in ice production (Lines 624–629 in the revised version). Meanwhile, the sentence “The main differences in the response of HSSW formation to the synoptic- and mesoscale cyclones lie in the persistent time of high-salinity signals after the cyclone decayed.” has been added in the revised version (Lines 632–633) to clarify the differences in HSSW formation between synoptic- and meso-scale cyclones.