## Anonymous Referee #1

Overview – this study investigates historical (1920-2000) and future (2000-2080) changes in near surface pressure and winds over the South Pacific using a combination of a spatially complete paleoclimate reconstruction and a large suite of climate model simulations. It provides convincing evidence of the relative roles of internal variability and forced variability (from greenhouse gases and ozone depletion). Importantly, the paper also provides a much-needed possible narrative for the roles of natural variability followed by external forcing to understand historical variations in ice loss from the WAIS since 1940s.

The paper is very well written, easy to follow, and the scientific analysis in my perspective is sound. The team is to be commended on this excellent study, which is well conceived and an important scientific advancement. The authors note many caveats to the present study, which I also appreciate.

My main concern is that the paper is primarily based on gridded model or paleoclimate-based reconstruction data, and does not incorporate the wealth of observations other than ERA5 after 1979. It would be helpful to see the agreement between the reconstruction at least and pressure observations (available across all SH midlatitudes since 1920, and Orcadas since 1903) to see at least the agreement in South America / South Atlantic. For more complete investigation on the agreement (and for some aspects of the deepening of the ASL), comparisons could be made with Antarctic data after 1957 when trends seem quite large (making note to include the critical point of Byrd station in West Antarctica as another potential estimate of observed change near the Amundsen Sea apart from measurements along the Antarctic Peninsula). I do feel the point observations comparisons with the reconstructions would help to understand changes in observations apart from paleoclimate data and climate model data, and would round out the paper well (1 more figure), and provide further validation for the reconstruction that is not provided in the preceeding O'Connor et al. paper.

O'Connor et al. (2021) validate their reconstruction against other paleoclimate reconstructions of the 20th century, modern reanalyses datasets (since 1979), and longer-term reanalyses (since 1900). The longer-term reanalyses are constrained primarily by the station data mentioned above. O'Connor et al. (2021) also show that their reconstructed SAM index compares favourably to that of Marshall (2003), which is based solely on station pressure observations from Antarctica and the sub-Antarctic regions since 1958. Thus the reconstruction has been validated using the earlier observations suggested by the reviewer. In any case, we see no immediate reason why the reconstruction's skill in fitting modern reanalysis data would not apply to earlier periods, since the proxy data underlying the reconstruction are uniformly available throughout the 20th century.

We agree that directly comparing the O'Connor et al. (2021) reconstruction to each of the station pressure records around Antarctica would add detailed insight into the quality of the reconstruction at those locations. However, the applicability of such a comparison to the present study is not clear because there are no long-term station data near the Amundsen Sea. It is not clear how far any direct misfit to remote stations such as Orcadas or South America should limit our confidence in reconstructed Amundsen Sea winds. (In the previous validations mentioned above, this issue is avoided by using the reanalysis model or SAM index to link such stations to the Amundsen Sea.) As a result we feel that a systematic comparison at station locations is certainly useful in general, but beyond the scope of the present paper.

To illustrate the issue of applicability of station data, we compared the reconstructed geostrophic winds used in the paper to geostrophic winds calculated from the surface pressure dataset of Fogt et al. (2019), which is constructed by interpolating Antarctic station pressure observations. Figure R1 shows an extended version of Figure 4 from the paper, to which the derived Fogt et al. (2019) winds have been added. The Fogt-derived winds are positively correlated to ERA5 over the deep ocean, but do not provide a useful constraint over the shelf break or shelf. (We speculate that negative correlations over the shelf reflect the Amundsen Sea Low, whose pattern is not captured by the spatial kriging in the Fogt dataset.) Over the deep ocean since 1957, the O'Connor and Fogt reconstructed winds are correlated, which is a very encouraging result considering the independent origin of these datasets. The level of correlation is similar to the fit between the O'Connor and Marshall SAM indices during that period (O'Connor et al., 2021). Prior to 1957 the fit between O'Conor and Fogt timeseries is much worse, which is unsurprising because the few direct station observations available during that period are extremely remote from the Amundsen Sea.

It is clear from the comments of both reviewers that the validation of the reconstructed winds is an important concern and needs to be better explained in the paper. We propose to add a new paragraph of text to section 2.1 detailing the various validation tests carried out by O'Connor et al. (2021) and

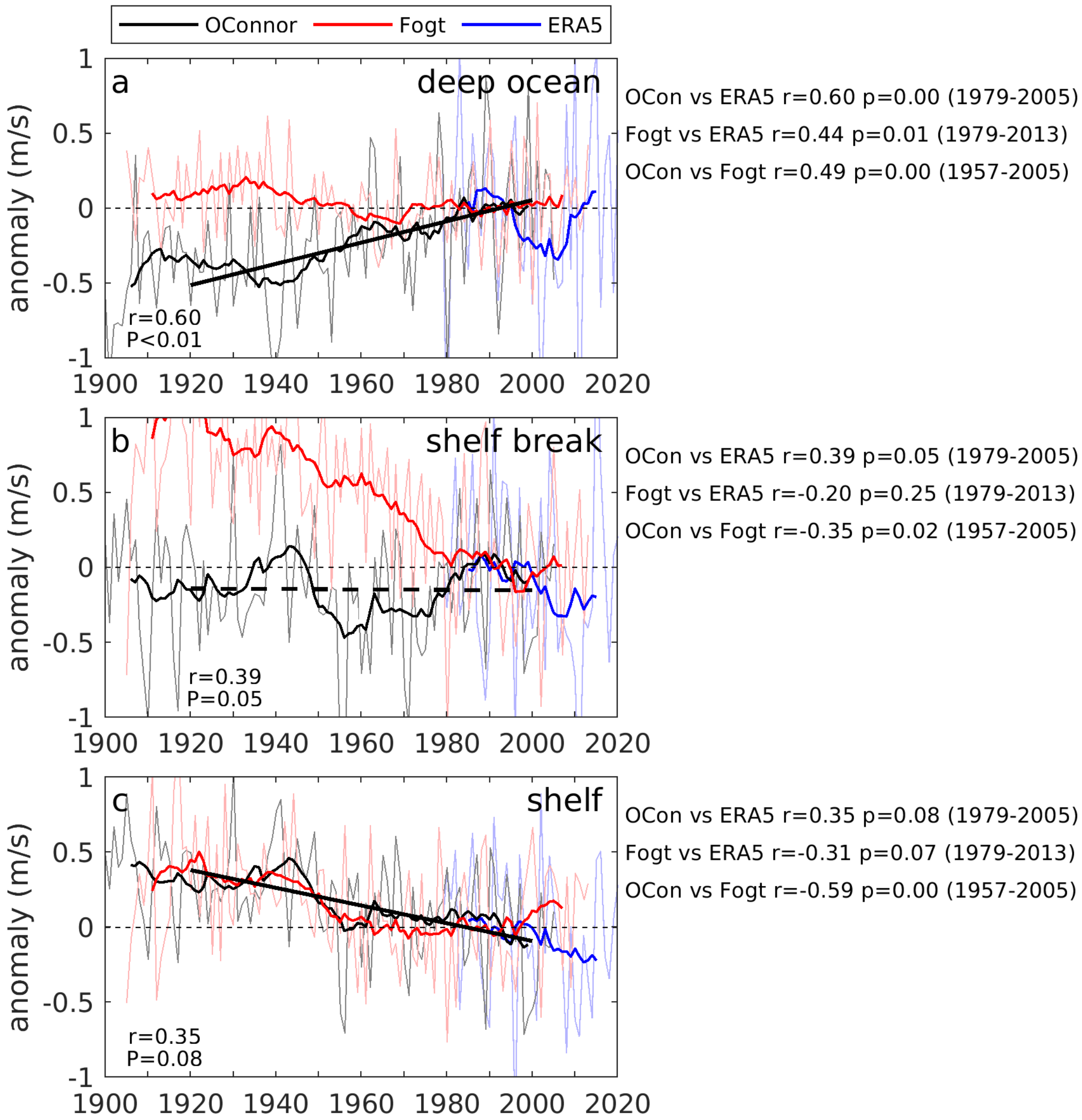


Figure R1: Copy of Figure 4 from the paper, but also containing zonal wind anomalies calculated from the Fogt et al. (2019) spatial interpolation of station pressure data.

presenting our rationale as to why these analyses support the use of the reconstruction in our study. We also propose to add some new text to section 3.1.3 detailing the statistics of our comparison of the reconstruction to the Fogt et al. (2019) dataset for winds over the Amundsen Sea. This will respond to the reviewer's comment by adding further text to the paper detailing the following points: i) Station data have previously been used to constrain the reconstruction through their influence on longer reanalyses and the Marshall SAM index; ii) Direct comparison of the reconstruction to station records would be a valuable step but will not necessarily constrain winds over the Amundsen Sea; iii) A new comparison to Fogt-reconstructed winds provides further station-based validation of the reconstructed winds over the deep ocean since 1958.

Minor comments:

Abstract – would be ideal to clarify the ice loss was not in reference to sea ice, but the grounded ice sheet

We will revise the text where needed.

L255-260, Fig. 1f – I also suspect the response to ozone is weaker as it is seasonally varying (strongest in DJF at the surface), so the annual mean reduces this signal.

We will add this point.

Wondering what role incorrect sea ice trends in the model may play in both the historical and future simulations? The climate model tends to overestimate observed sea ice trends compared to observations. Importantly, the sea ice trends have been most pronounced in the Pacific sector in observations, which is the area of study, so it is possible that there could be some impact of this on the pressure and wind trends in the region from the model, especially in the model ensemble means. Can the authors comment on this potential error, where appropriate, in the paper?

Since the advent of continuous satellite observations in 1979, sea-ice trends have been focussed on the Pacific sector of the Southern Ocean as a result of internal variability. The trends are driven by a negative trend in the IPO since the 1980s (Meehl et al., 2016; Purich et al., 2016). Holland et al (2019) and Schneider and Deser (2018) show that that the CESM1 is able to accurately represent this pattern of internally-generated variability over this part of the South Pacific. So there is no additional cause for concern in this region.

Overall, however, Schneider and Deser (2018) show that historical CESM1 simulations do feature an unrealistic circum-Antarctic trend of sea-ice loss since 1979. This ice loss is associated with excessive ocean surface warming, suggesting that the model does not subduct heat efficiently into the Southern Ocean interior. Such ocean model biases are the reason we focus on winds in this study as a proxy for ocean history in the Amundsen Sea, rather than considering the ocean model results directly.

These sea ice and SST trend biases do not seem to heavily influence model winds. Since 1979, the CESM1 accurately represents trends in the Amundsen Sea Low (England et al., 2016), wind trends over the Amundsen Sea (Holland et al., 2019), and the pattern of pressure trends over the South Pacific (Schneider and Deser, 2018). Thus, we are not unduly concerned about the sea ice and SST biases.

It remains possible that the model has an excessive wind response to external forcing over the longer time period since 1920. This cannot be validated directly against observations, since the real wind history combines both externally-forced and internally-generated changes. We can only note that the CESM1 externally-forced wind trends are representative of the wider CMIP5 ensemble in this region

(Holland et al 2019), and the ensemble of CESM1 historical trends comfortably includes the reconstructed historical trends (figure 3).

Model biases are discussed from line 166 onwards, including mention of previous work on the model's ability to represent sea-ice trends during recent decades (Schneider and Deser, 2018), so we will expand that discussion to include the relevant points: i) Overall, the CESM1 does contain biased sea ice trends in recent decades; ii) There is no additional cause for concern in the region of interest to this study; iii) The sea ice biases do not appear to be associated with wind biases; iv) The model is not an outlier in this regard.

L595-603 – really appreciate mentioning the caveats to the study. I think it is also important to mention that the study masks seasonal variability, limited by the paleoclimate reconstruction, that is important for tropical teleconnections (i.e., internal variability) and the role of ozone forcing.

We will add this point.

## References

Fogt, R. L., Schneider, D. P., Goergens, C. A., Jones, J. M., Clark, L. N., and Garberoglio, M. J.: Seasonal Antarctic pressure variability during the twentieth century from spatially complete reconstructions and CAM5 simulations, Climate Dynamics, 53, 1435–1452, 10.1007/s00382-019-04674-8, 2019.

Marshall, G. J.: Trends in the Southern Annular Mode from observations and reanalyses, Journal of Climate, 16, 4134-4143, 2003.

Meehl, G. A., Arblaster, J. M., Bitz, C. M., Chung, C. T. Y., and Teng, H. Y.: Antarctic sea-ice expansion between 2000 and 2014 driven by tropical Pacific decadal climate variability, Nature Geoscience, 9, 590-+, 10.1038/Ngeo2751, 2016.

O'Connor, G. K., Steig, E. J., and Hakim, G. J.: Strengthening Southern Hemisphere westerlies and Amundsen Sea Low deepening over the 20th century revealed by proxy-data assimilation, Geophysical Research Letters, 48, e2021GL095999, 10.1029/2021GL095999, 2021.

Purich, A., England, M. H., Cai, W., Chikamoto, Y., Timmermann, A., Fyfe, J. C., Frankcombe, L., Meehl, G. A., and Arblaster, J. M.: Tropical Pacific SST Drivers of Recent Antarctic Sea Ice Trends, Journal of Climate, 29, 8931-8948, 10.1175/Jcli-D-16-0440.1, 2016.