

Dear Dr. King,

We would like to sincerely thank you for your constructive and insightful comments on the initial version of our manuscript. Below, we provide detailed point-by-point responses to each of your comments. The Referees' remarks are shown in italics, and our responses are provided in plain blue font.

#### *General remarks*

*The meteorological observing network in high southern latitudes is sparse and very few continuous series of observations extend back beyond the International Geophysical Year of 1957/58. For these reasons, studies of interdecadal climate variability and long-term change in the Antarctic regions have relied heavily on atmospheric reanalyses, such as ERA5. Such reanalyses provide a good representation of atmospheric circulation and surface climate from 1979 to the present day. Over this period, satellite sounder data provide a strong constraint on atmospheric circulation, and other satellite observations provide a good reconstruction of sea surface conditions (SSCs, sea surface temperatures and sea ice conditions). It is therefore not surprising that atmospheric reanalyses perform less well over the pre-1979 period when satellite data were not available. In particular, reanalyses show a systematic cold bias in Antarctic surface temperatures (relative to observations) over the pre-1979 period which is smaller or absent in the later period, leading to an artificial warming trend in the reanalysis.*

*In this paper, the authors carry out a series of experiments with an atmospheric model forced by a new reconstruction of pre-1979 Southern Ocean SSCs to investigate whether errors in the representation of SSCs in ERA5 are responsible for the pre-1979 cold bias in that reanalysis. They conclude that SSC uncertainties in the earlier period could account for around 30% of the cold bias but other factors must also be contributing.*

*The paper is well-written and clearly explains the methodology, which exploits a reconstruction of pre-satellite SSCs developed by the lead author. The conclusions are soundly based on the results of the model experiments. I believe that the paper is suitable for publication in *The Cryosphere* after the (mostly minor) comments below have been addressed.*

[We thank the referee for the overall positive feedback on our study.](#)

#### *General comments*

*1. The study is aimed at identifying whether the cold Antarctic bias in ERA5 during the pre-satellite era is a result of errors in specified SSCs. Ideally, one would investigate this by rerunning part of the ERA5 reanalysis with an alternative SSC dataset, but this would be prohibitively expensive so an alternative approach is taken where an atmospheric model is run with both ERA5 and alternative SSCs. This is a fairly standard approach to investigating model sensitivity and, as such, is valuable in itself. However, it is important to recognise that there are differences between CAM and the IFS model which was used to produce ERA5, both in the dynamical core and in the physical parametrisations used. I am not familiar with CAM so I don't know how large these differences could be, but I think that there should be*

*some discussion of this in the paper. Secondly, while CAM is only constrained by, the imposed SSCs, ERA5 is additionally constrained by atmospheric observations. This point should also be noted.*

We thank the referee for this relevant comment regarding the differences between CAM and the IFS model. We agree that re-running the ERA5 reanalysis with alternative SSC datasets would be the ideal approach to quantify the impact of sea surface conditions on Antarctic climate in ERA5, but this is currently not feasible (in terms of computation resources and practical access). As stated by the referee, our study adopts a standard AMIP-style sensitivity framework to isolate the atmospheric response to SSC uncertainties using two alternative SSC datasets. We would like to emphasize that our primary objective is to assess the contribution of SSC uncertainty on Antarctic surface climate.

We acknowledge that CAM and the IFS model differ in their dynamical cores and physical parameterizations, and that these structural differences may influence the simulated response to SSC forcing.

We will revise the manuscript to explicitly discuss the structural differences between the two models and clarify that our findings reflect the response of CAM to prescribed SSCs. We will also adopt more cautious language when discussing the contribution of SSCs to the cold bias in ERA5, and expand the discussion on the role of increasing observational constraints in ERA5, in particular during the late 1970s, as highlighted by Bromwich et al. (2024). Finally, we will further emphasize that our main objective is to assess SSC-related uncertainty rather than to reproduce ERA5 variability.

*2. The authors conclude from their model experiments that around 30% of the Antarctic cold bias in ERA5 could result from errors in pre-satellite SSCs. This is quite a precise statement and, in order to support it, I would like to see some discussion of the uncertainties in the reconstructed SSC product. Is it possible to quantify the uncertainties? Would it be possible to examine the impact of these uncertainties on simulated Antarctic temperatures through a series of perturbed model runs? While I agree with the authors that “Developing a temporally-consistent SSC dataset for the high-latitude southern hemisphere is therefore a priority” (lines 194-195) the lack of satellite observations before 1979 means that the uncertainties in SSCs during the earlier period will always be higher than post-1979. Quantifying simulation uncertainty resulting from uncertainty in SSC reconstructions is thus very important.*

We thank the referee for this important comment regarding the uncertainty associated with our estimate that SSC errors account for about 30% of the Antarctic cold bias in ERA5. We acknowledge that this estimate is dependent on the framework and reflects the response of CAM to the specific SSC datasets considered, as well as uncertainties in the alternative SSC reconstruction (i.e., ANT-REC). We therefore agree that this value should be interpreted cautiously, and we will revise the manuscript to clearly state that it applies within the context of our experimental design.

Our ensemble of ten CAM simulations for each forcing dataset was designed to quantify the influence of internal atmospheric variability. As shown in the manuscript, the ensemble members exhibit very similar responses, indicating that the reported differences primarily

reflect SSC forcing rather than atmospheric initialization. However, we acknowledge that our experimental design does not directly quantify uncertainties in the SSC reconstructions themselves.

ANT-REC is based on the data assimilation of Antarctic and sub-Antarctic atmospheric pressure and temperature records into Earth System Model simulations, followed by ocean–sea-ice modeling to explicitly represent ocean dynamics. While ten atmospheric reconstructions are available, only the CESM1-based reanalysis was used to force the ocean–sea-ice model in Dalaiden et al. (2025). To provide an indication of SSC uncertainty, we therefore compare ANT-REC with the other available atmospheric reanalyses and with the independent reconstruction of Fogt et al. (2022), which shows a weaker pre-1979 sea-ice decline ( $0.18 \times 10^6 \text{ km}^2$  between 1959–1968 and 1981–2000, compared with  $0.49 \times 10^6 \text{ km}^2$  for ANT-REC). Among the ten atmospheric reanalyses, the CESM1-based atmospheric reanalysis shows a sea-ice extent change of  $0.40 \times 10^6 \text{ km}^2$ , which lies within the range of the other reconstructions ( $0.41 \pm 0.18 \times 10^6 \text{ km}^2$ ). This indicates that the CESM1-based reanalysis is not exceptional, but close to the ensemble mean. In addition, as highlighted by Goosse et al. (2024) and Dalaiden et al. (2025), ANT-REC is broadly consistent with independent paleo-based estimates (Thomas et al., 2019; Dalaiden, Rezsóhazy et al., 2023). These studies also suggest that the reconstruction of Fogt et al. (2022) may underestimate pre-1979 sea-ice changes due to methodological limitations. We will expand the manuscript to better quantify and discuss these uncertainties and their implications for Antarctic climate sensitivity.

Finally, we agree with the referee that SSC uncertainties prior to 1979 will inevitably remain larger than in the period after 1979. Nevertheless, we believe that combining multiple information sources, including early satellite data, weather stations, ship observations, and paleoclimate records, offers a promising pathway toward improved historical SSC reconstructions. We will expand the discussion accordingly in the revised manuscript.

#### *Specific comments*

1. L20 (and elsewhere): Replace “transport of humidity” with “transport of moisture”.
2. L46-49: The description of the ERA5 SSC dataset is a bit confusing. Maybe something like “The first dataset is taken directly from ERA5, which uses the HadISST2 dataset before 1979 and the OSTIA product thereafter” would be clearer?
3. L49-50: It is not clear what period you are referring to here.
4. L120-122: It is not clear how the bootstrap subsamples were extracted.
5. L125: “positive” rather than “negative”?
6. Figure 2: It is difficult to see the location of Faraday on the map. Also, note that Faraday was renamed Vernadsky in 1996 following its transfer to the Ukrainian Antarctic Programme.
7. L137 “with respect to...”

We thank the referee for these helpful and detailed comments. We will carefully implement each point by incorporating all suggested corrections and providing clarifications where needed.