Response Letter

Dear Editor and Reviewers:

We greatly appreciate your efforts in reviewing the previous version of the manuscript (Title: Comprehensive evaluation of iAMAS (v1.0) in simulating Antarctic meteorological fields with observations and reanalysis, Manuscript ID: gmd-2024-229). We have made point-to-point responses to all the comments/suggestions raised in your review reports and made the corresponding revisions in the manuscript. All the replies in this document are colored in blue, and the revisions/changes in the revised manuscript are marked in red.

RC1: Anonymous Referee #1, 02 Mar 2025

In this paper, the authors employ the integrated Atmospheric Model Across Scales (iAMAS) with four unstructured mesh configurations (resolutions of 120 km, 60 km, 16 km, and 4 km) to simulate Antarctic meteorological conditions and compare the results against both ERA5 reanalysis data and in situ measurements (AWS and radiosondes). Their findings highlight that unstructured meshes avoid the "polar singularity" problem seen in ERA5 at the South Pole, where ERA5 substantially underestimates wind speeds. In relatively flat Antarctic regions, iAMAS at coarse resolutions (e.g., 60 km) already achieves performance comparable to—or better than—ERA5, suggesting that high-resolution meshes offer minimal additional benefits there. Conversely, over complex terrain such as the Transantarctic Mountains, higher-resolution grids (around 4 km) significantly improve the simulation of temperature, pressure, specific humidity, and wind speed, reducing the systematic cold and wind biases found in coarser configurations. Overall, this study underscores the advantages of unstructured meshes for polar modeling, particularly in resolving complex topography, while also showing that moderate resolutions may suffice in more uniform terrain.

The paper is well written and organized. It would be a contribution to the journal GMD. However, there are some minor issues where further explanation is needed to improve the manuscript's quality. I suggest minor revisions to the manuscript before it is accepted for publication.

Response:

We thank the Reviewer for providing us very detailed and useful comments, which have been instrumental in enhancing the quality and clarity of our manuscript. We have carefully considered all the comments and have made comprehensive revisions to address each point raised. Our detailed responses to the Reviewers' comments are provided below.

- ***Major comments***

  One of my main concerns is that the authors did not show any comparison regarding snowfall estimation. As mentioned in the introduction, ice sheet simulation is why accurate polar atmospheric simulations are needed. Then it is necessary to understand how different model configurations affect the amount and distribution of snow. If precipitation observation is available, the authors should compare their simulation results with the observation. Even if the observation data do not have a precipitation record, analyzing simulation results

and how different resolutions affect the precipitation pattern and intensity would still be helpful.

Response:

Thank you for the reviewer's suggestions. We agree to analyzing the snowfall simulations, and found that Antarctic snowfall primarily occurs over the ocean surrounding the continent rather than on the continent (see Fig. S1). The Antarctic interior experiences significantly less snowfall, consistent with the findings of Andrew et al. (2006), Arthern et al. (2006), and Bromwich (1988).

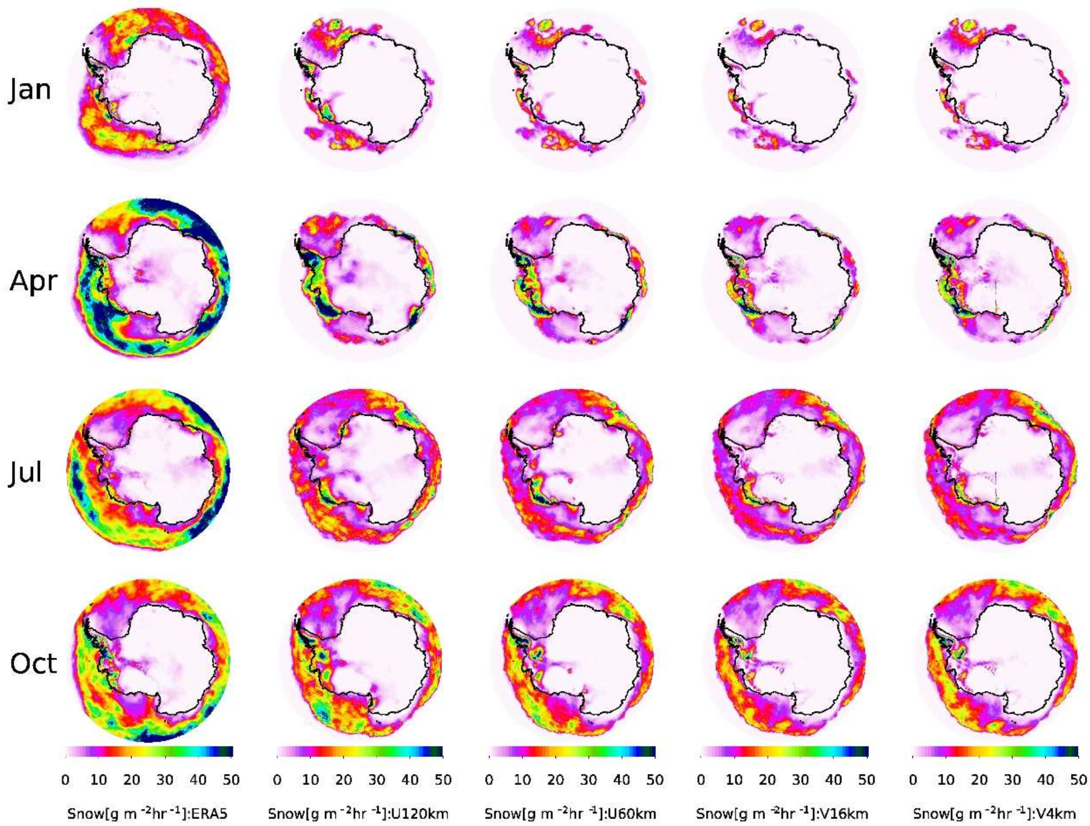

Figure S1. The first column displays the monthly median snowfall (Snow[g m^{-2} $hour^{-1}$]) from ERA5. The four rightmost columns show the monthly median values of snowfall (Snow[g m^{-2} $hour^{-1}$]) from iAMAS with four mesh resolutions.

This study focuses on the meteorological conditions over the Antarctic continent, as the refined grid is centered over the Antarctic continent. Snowfall primarily occurs over the surrounding ocean and may have minor impact on the meteorological conditions of the Antarctic Plateau. Therefore, we will provide only a brief analysis of snowfall in the revised manuscript, while the results of Antarctic snowfall simulations will be presented in the supplementary information rather than in the main text. Additionally, in the original manuscript, our discussion of snow's impact on meteorological conditions referred to blowing snow lifted from the surface rather than snowfall from the sky. Blowing snow, characterized by the transport of snow by wind, plays a crucial role in snow accumulation in Antarctica (e.g., Trouvilliez A., 2013). We will revise our description accordingly to clarify this distinction.

Snowfall observations are not available; only temperature, pressure, wind, and humidity data are provided (see ftp://amrc.ssec.wisc.edu/pub/aws/q3h/q3hreadme.txt). Therefore, we cannot compare the simulation results with snowfall observations. Nevertheless, the snowfall simulations from iAMAS will be compared with ERA5.

As seen in Fig. S1, both iAMAS and ERA5 results indicate that snowfall primarily occurs over the ocean surrounding the Antarctic Plateau. There is little snowfall over the Antarctic Plateau, with only some occurring in West Antarctica, particularly over the Antarctic Peninsula, consistent with the findings of Arthern et al. (2006) and the results of ERA5 (see the first column in Fig. S1).

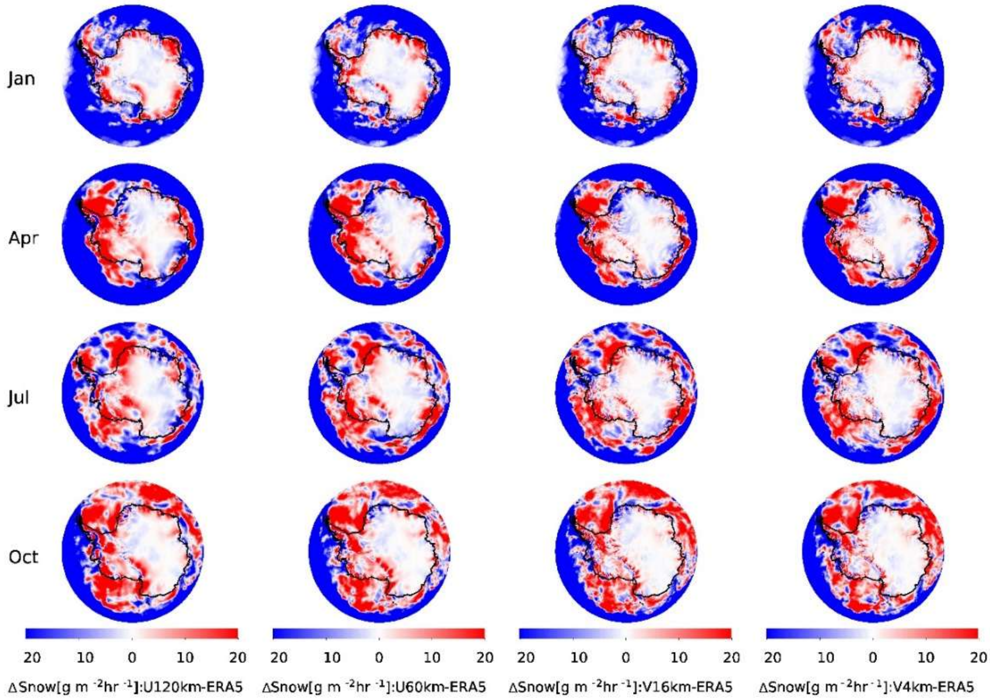

Figure S2. Monthly mean values of snowfall biases (ΔSnow [g m-2 hour-1]) for iAMAS minus ERA5. The mean values were used instead of the median values because there are many zero values in the snowfall data set.

Compared to ERA5, iAMAS generally overestimates snowfall over the Antarctic Plateau while significantly underestimating it over the ocean (see Fig. S2). This underestimation appears to be primarily associated with water surface, as the snowfall underestimation pattern closely resembles sea ice extent (Casagrande et al., 2023). This issue over the water surface is somewhat beyond the scope of this manuscript, since this study focuses on the Antarctic continent. It warrants further investigation when snowfall measurements over the ocean surrounding the Antarctic Plateau are available.

When comparing iAMAS simulations at different resolutions, Fig. S2 shows that increasing grid resolution reduces snowfall overestimations over West Antarctica. Snow formation is closely related to humidity, the improvement in snowfall simulation with higher grid resolution in complex terrain is consistent with the humidity profile results (see Sect. 3.2.3 in the revised manuscript).

Revision in the manuscript:

We have replaced

"However, maintaining the sensors at a fixed height is challenging due to snow accumulation at many sites (Lazzara et al., 2012)."

with

"Maintaining sensors at a fixed height is challenging due to snow accumulation at many sites (Lazzara et al., 2012). Blowing snow, characterized by the transport of snow by wind, plays a crucial role in snow accumulation in Antarctica. In contrast, snowfall from the sky appears to have a relatively minor contribution, as both iAMAS and ERA5 indicate that the Antarctic interior experiences significantly small snowfall (see Fig. S1 in the supplementary information). Moreover, the differences in snowfall between iAMAS and ERA5 across the Antarctic continent are relatively small (see Fig. S2 in the supplementary information)."

in the revised manuscript (lines 178-183, pages 8-9).

We have replaced

"Similar dry biases were also noted in AMPS simulations (Wille et al., 2016), suggesting that this underestimation may arise from the Unified Noah Land Surface Model (also utilized by iAMAS in this study), which does not account for sublimation from blowing snow."

with

"Similar dry biases were also noted in AMPS simulations (Wille et al., 2016), which suggested that this underestimation may arise from the Noah LSM, which is also used by iAMAS in this study. The Noah LSM does not account for sublimation from drifting and blowing snow near the surface."

in the revised manuscript (lines 281-283, page 14).

We have added

"Snow formation is closely related to humidity. Comparing ERA5 snowfall with iAMAS simulations shows that increasing iAMAS grid resolution reduces snowfall overestimations over the complex terrain of West Antarctica (see Fig. S2 in the supplementary information)."

in the revised manuscript (lines 436-438, page 24).

We have added

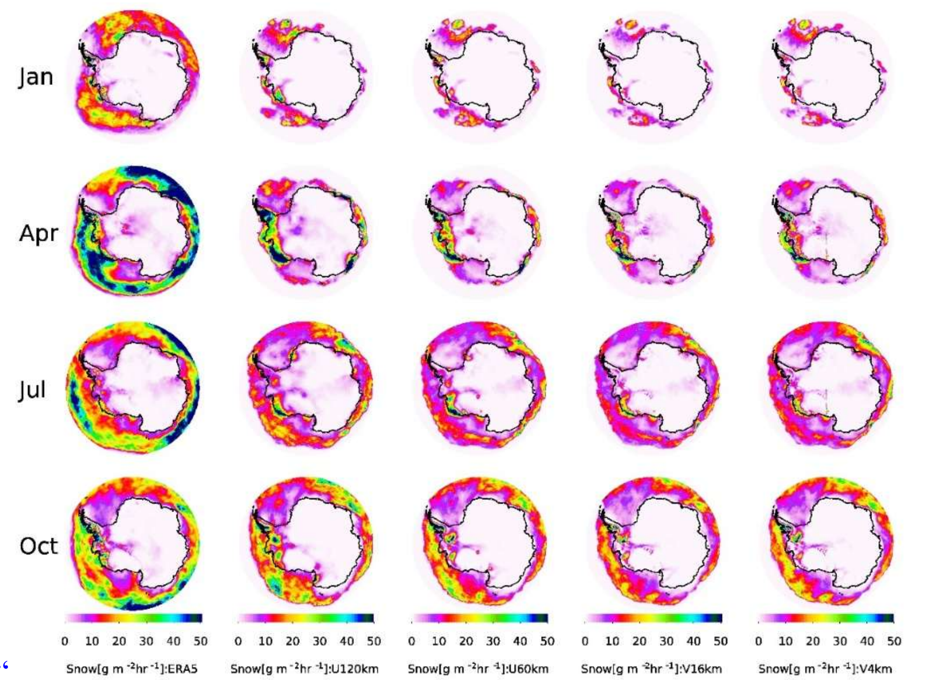

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Figure S1. The first column displays the monthly median snowfall (Snow[g m^{-2} $hour^{-1}$]) from ERA5. The four rightmost columns show the monthly median values of snowfall (Snow[g m^{-2} $hour^{-1}$]) from iAMAS with four mesh resolutions.”

in the revised supplement information (Figure S1).

We have added

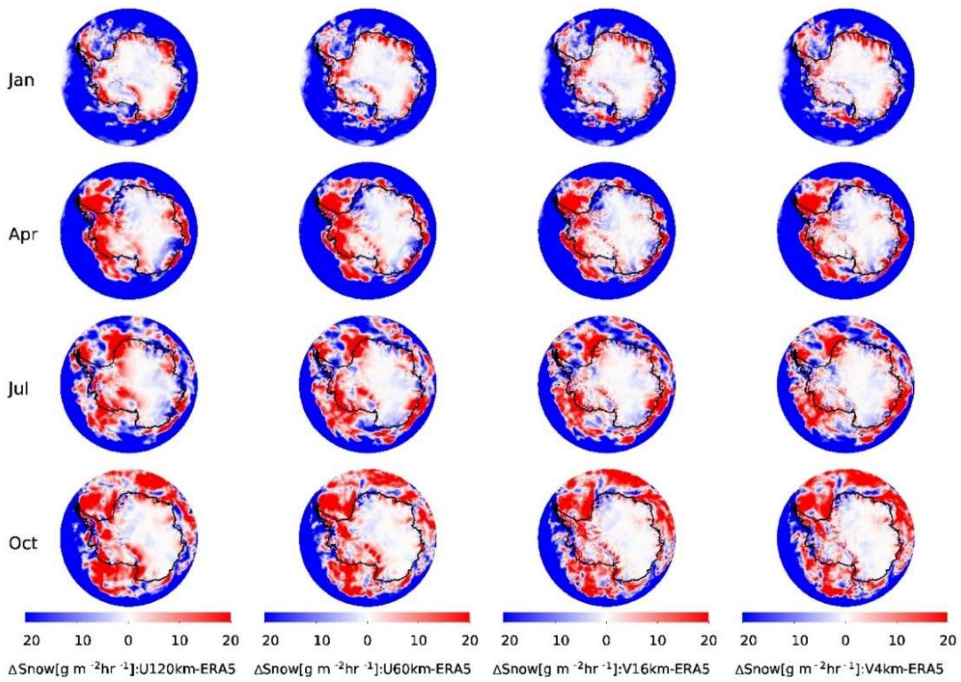

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Figure S2. Monthly mean values of snowfall biases (ΔSnow[g m^{-2} $hour^{-2}$]) for iAMAS minus ERA5. The mean values were used instead of the median values because there are many zero values in the snowfall datasets.”

in the revised supplement information (Figure S2).

References:

Andrew J Monaghan, David H Bromwich, and Sheng-Hung Wang. (2006), Recent trends in Antarctic snow accumulation from Polar MM5 simulations, Phil. Trans. R. Soc. A, 364, 1683–1708, doi:10.1098/rsta.2006.1795

Arthern, R. J., D. P. Winebrenner, and D. G. Vaughan (2006), Antarctic snow accumulation mapped using polarization of 4.3-cm wavelength microwave emission, J. Geophys. Res., 111, D06107, doi:10.1029/2004JD005667.

Bromwich, D. H. (1988), Snowfall in high southern latitudes, Rev. Geophys., 26(1), 149–168, doi:10.1029/RG026i001p00149

Casagrande, F., Stachelski, L., & de Souza, R. B. (2023). Assessment of Antarctic sea ice area and concentration in Coupled Model Intercomparison Project Phase 5 and Phase 6 models. International Journal of Climatology, 43(3), 1314–1332. https://doi.org/10.1002/joc.7916

Lazzara, M. A., Weidner, G. A., Keller, L. M., Thom, J. E., and Cassano, J. J.: Antarctic Automatic Weather Station Program: 30 Years of Polar Observation, Bulletin of the American Meteorological Society, 93, 1519–1537, https://doi.org/10.1175/bams-d-11-00015.1, 2012.

Trouvilliez A., Naaim-Bouvet F., Genthon C., et al. (2013). Blowing snow in Antarctica: 3 years of continuous observations in Adélie Land. International Snow Science Workshop (ISSW), Oct 2013, Grenoble- Chamonix Mont-Blanc, France. p. 1327- p. 1331. hal-00951148

- ***The second point I think the author should elaborate on is the stratospheric wind bias (Fig. 8). I don't feel the authors' explanation is convincing enough. ERA5 clearly does not have similar issues. Is the cause the relatively low model top? It appears to me that a high-top model like WACCM is necessary if we want to get the stratosphere simulation correct. I hope the authors can provide more explanations and references in this section.***

Response:

We appreciate the reviewer's comment and agree to include a discussion on the impact of the high- and low-top models. Accordingly, we have added additional discussion and references in the revised manuscript to explain how the vertical domain influences simulation performance.

The iAMAS model lid used in this study is set at approximately 10 hPa, classifying it as a low-top model. In contrast, high-top atmospheric models, with a model top at or above 1 hPa, have been shown to produce more accurate simulations of winds and temperatures, as evidenced by global atmospheric modeling evaluations (Lawrence et al., 2022; Zhao et al., 2016). Regarding polar simulation studies, the Whole Atmosphere Community Climate Model—a high-top model—demonstrates improvements over the low-top version of the Community Atmosphere Model (CAM) (Gettelman et al., 2019). In addition, for the Southern Hemisphere polar vortex final warming date, ensembles of high-top models from the fifth Coupled Model Intercomparison Project (CMIP5) show better agreement with reanalysis data than low-top ensembles (Wilcox & Charlton-Perez, 2013). Thus, employing a high-top model may enhance stratospheric simulation accuracy in Antarctica.

Revision in the manuscript:

We have replaced

"This high-altitude temperature bias may be partly due to the lack of radiosonde measurements, as extreme cold temperatures in Antarctica increase the likelihood of sounding balloons bursting. Consequently, model errors tend to increase in the absence of measurements constraints, as observed by ERA5, which also exhibits a tendency to produce larger temperature errors at high altitudes."

with

"The model lids for both iAMAS and AMPS are set at approximately 10 hPa, classifying them as low-top models. In contrast, high-top atmospheric models, with a model top at or above 1 hPa, have been shown to produce more accurate simulations of winds and temperatures, as demonstrated by global atmospheric modelling evaluations (Lawrence et al., 2022; Zhao et al., 2016). Regarding polar simulation studies, the Whole Atmosphere Community Climate Model—a high-top model—exhibits improvements over the low-top version of the Community Atmosphere Model (CAM; Gettelman et al., 2019). In addition, for the Southern Hemisphere polar vortex final warming date, ensembles of high-top models from the fifth Coupled Model Intercomparison Project (CMIP5) show better agreement with reanalysis data than low-top ensembles (Wilcox and Charlton-Perez, 2013). Thus, employing a high-top model may enhance the accuracy of stratospheric simulations in Antarctica."

in the revised manuscript (lines 357-365, pages 18-20).

We have replaced

"Similar to the upper-air temperature (Section 3.2.1), this high-altitude wind speed bias may also be partly due to the lack of radiosonde measurements for model constraints."

with

"The high-altitude wind speed biases may also be partly attributed to the limitations of the low-top version of the iAMAS model used in this study. This study primarily focuses on tropospheric simulations, which appear to be more sensitive to model grid resolution, while research on high-altitude stratospheric simulations is currently ongoing."

in the revised manuscript (lines 463-466, page 26).

References:

Lawrence, Z. D., M. Abalos, B. Ayarzagüena, D. Barriopedro, A. H. Butler, N. Calvo, A. de la Cámara, A. Charlton-Perez, D. I. V. Domeisen, E. Dunn-Sigouin, J. García-Serrano, C. I. Garfinkel, N. P. Hindley, L. Jia, M. Jucker, A. Y. Karpechko, H. Kim, A. L. Lang, S. H. Lee, P. Lin, M. Osman, F. M. Palmeiro, J. Perlwitz, I. Polichtchouk, J. H. Richter, C. Schwartz, S. W. Son, I. Erner, M. Taguchi, N. L. Tyrrell, C. J. Wright, and R. W. Y. Wu. 2022. 'Quantifying stratospheric biases and identifying their potential sources in subseasonal forecast systems', Weather Clim. Dynam., 3: 977-1001.

Zhao, L. L., J. J. Xu, A. M. Powell, Z. H. Jiang, and D. H. Wang. 2016. 'Use of SSU/MSU Satellite Observations to Validate Upper Atmospheric Temperature Trends in CMIP5 Simulations', Remote Sensing, 8: 1-16.

Gettelman, A., M. J. Mills, D. E. Kinnison, R. R. Garcia, A. K. Smith, D. R. Marsh, S. Tilmes, F. Vitt, C. G. Bardeen, J. McInerny, H. L. Liu, S. C. Solomon, L. M. Polvani, L. K. Emmons, J. F. Lamarque, J. H. Richter, A. S. Glanville, J. T. Bacmeister, A. S. Phillips, R. B. Neale, I. R. Simpson, A. K. DuVivier, A. Hodzic, and W. J. Randel. 2019. 'The Whole Atmosphere Community Climate Model Version 6 (WACCM6)', Journal of Geophysical Research-Atmospheres, 124: 12380-403.

Wilcox, L. J., and A. J. Charlton-Perez. 2013. 'Final warming of the Southern Hemisphere polar vortex in high- and low-top CMIP5 models', Journal of Geophysical Research-Atmospheres, 118: 2535-46.

- ***Minor comments:***

  Line 45: It is better to mention cubed sphere grid as an alternative option. Are there polar simulation studies using the cubed sphere (like FV3)?

Response:

We thank the reviewer for this suggestion. We agree to mention the cubed-sphere grid, as it provides an alternative approach to avoiding the polar grid singularity. Cubed-sphere models such as FV3 (Putman & Lin, 2007; Harris & Lin, 2013) have been used in a few polar simulation studies, e.g., sea ice extent simulations (Guo et al., 2020; Held et al., 2019). Some other global simulations employing the cubed-sphere grid have only briefly mentioned polar simulations, as they focus on refining grid meshes in the middle and low latitudes rather than on polar regions (e.g., Harris, Lin, & Tu, 2016; Harris & Lin, 2014; Tang et al., 2023).

Revision in the manuscript:

We have added

"The iAMAS model employs a hexagonal sphere grid. Some other global models use cubed-sphere grids, such as FV3 (Putman and Lin, 2007; Harris and Lin, 2013), which have been applied in a few polar simulation studies, such as sea ice extent simulations (Guo et al., 2020; Held et al., 2019). However, most global simulations utilizing the cubed-sphere grid have only briefly mentioned polar regions, as their primary focus has been on mesh refinement over middle and low latitudes (e.g., Harris et al., 2016; Harris and Lin, 2014; Tang et al., 2023)."

in the revised manuscript (lines 47-52, page 2).

References:

Putman, William M., and Shian-Jiann Lin. 2007. 'Finite-volume transport on various cubed-sphere grids', Journal of Computational Physics, 227: 55-78.

Harris, L. M., and S. J. Lin. 2013. 'A Two-Way Nested Global-Regional Dynamical Core on the Cubed-Sphere Grid', Monthly Weather Review, 141: 283-306.

Guo, Y. Y., Y. Q. Yu, P. F. Lin, et al. 'Simulation and Improvements of Oceanic Circulation and Sea Ice by the Coupled Climate System Model FGOALS-f3-L', ADVANCES IN ATMOSPHERIC SCIENCES, 37: 1133-48.

Held, I. M., H. Guo, A. Adcroft, et al. 2019. 'Structure and Performance of GFDL's CM4.0 Climate Model', Journal of Advances in Modeling Earth Systems, 11: 3691-727.

Harris, L. M., S. J. Lin, and C. Y. Tu. 2016. 'High-Resolution Climate Simulations Using GFDL HiRAM with a Stretched Global Grid', Journal of Climate, 29: 4293-314.

Harris, L. M., and S. J. Lin. 'Global-to-Regional Nested Grid Climate Simulations in the GFDL High Resolution Atmospheric Model', Journal of Climate, 27: 4890-910.

Tang, Q., J. C. Golaz, L. P. Van Roekel, et al. 2023. 'The fully coupled regionally refined model of E3SM version 2: overview of the atmosphere, land, and river results', Geoscientific Model Development, 16: 3953-95.

- ***Line 97-98: Why is the center of the 4-km grid mesh not centered at the south pole? What is the justification? What is unique about 80 degree S and 160 degree E?***

Response:

Thank you for the reviewer's questions. We agree to explain the reason behind centering the 4-km grid mesh at 80°S, 160°E. Regarding the center of the 4-km grid mesh not being located at the South Pole, this is because 80°S, 160°E lies over complex terrain, specifically the Transantarctic Mountains. High-resolution grids are generally required for regions with complex terrain. We aim to clarify that increasing grid resolution is particularly necessary for complex terrain, whereas it is less critical for flat terrain. For V16km, the 16-km grid mesh is centered at the South Pole and encompasses the entire Antarctic continent, whereas V4km covers only the Transantarctic Mountains rather than the entire continent. In the revised manuscript, we have added an explanation for why 80°S, 160°E was chosen as the center of the 4-km grid mesh.

Revision in the manuscript:

We have replaced

"The second variable-resolution mesh also features a circular refined region but with a 4-km resolution (V4km), centered at 80°S, 160°E."

with

"The second variable-resolution mesh also features a circular refined region but with a 4-km resolution (V4km), centered at 80°S, 160°E, covering the complex terrain of the Transantarctic Mountains, as high-resolution grids are generally required for complex terrain."

in the revised manuscript (lines 104-106, page 4).

- ***Line 192-194: It is good that iAMAS exhibits more accurate temperature result. However, what is the physical reason for the better performance? The author should give some explanation, or at least speculation here.***

Response:

Thank you for the reviewer's suggestions. We agree to explain the potential reasons behind the better performance of iAMAS. The poorer performance of ERA5 can be attributed to its overestimation of surface turbulent heat fluxes under stable conditions (Fréville et al., 2014). To further investigate, we compared the turbulent heat fluxes between iAMAS and ERA5 under stable conditions for the four months (January, April, July, and October) at the SP. We found that the surface turbulent sensible heat flux in iAMAS (e.g., V4km: 20.4 W m^{-2}) is lower than in ERA5 (28.4 W m^{-2}) during temperature inversion (see Fig. R1 in this response letter). In summary, these results suggest that iAMAS may not overestimate the surface turbulent heat flux like ERA5, potentially simulating more accurate turbulent heat fluxes, leading to more accurate temperature simulations.

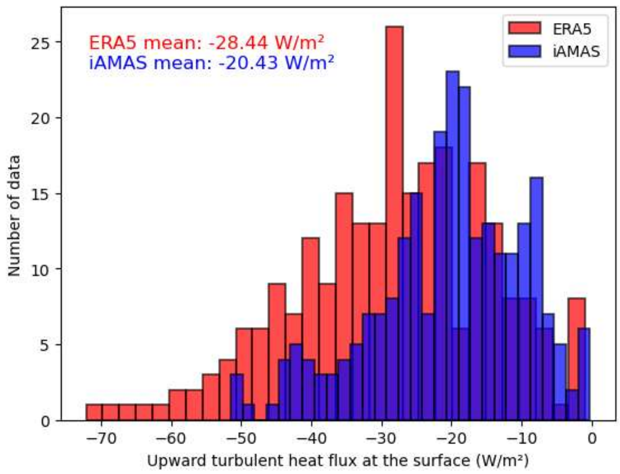

Figure R1. Histogram of surface turbulent heat fluxes between ERA5 and iAMAS

Revision in the manuscript:

We have replaced

"This confirms that ERA5 demonstrates inaccurate temperature estimations under inversion conditions in Antarctica. While iAMAS does not exhibit the overestimation of stable stratification temperature observed in ERA5, suggesting that iAMAS more accurately represents the surface temperature"

with

"This confirms that ERA5 demonstrates inaccurate temperature estimations under inversion conditions in Antarctica. By comparing the turbulent heat fluxes between iAMAS and ERA5 under stable conditions for four months (January, April, July, and October) at the SP, we found that the surface turbulent sensible heat flux in iAMAS (e.g., V4km: 20.4 W m^{-2}) is lower than in ERA5 (28.4 W m^{-2}) during temperature inversion. These results suggest that, unlike ERA5, iAMAS may not overestimate surface turbulent heat fluxes, potentially leading to more accurate temperature predictions."

in the revised manuscript (lines 212-217, pages 9-10).

References:

Fréville, H., E. Brun, G. Picard, N. Tatarinova, L. Arnaud, C. Lanconelli, C. Reijmer, and M. van den Broeke. 2014. 'Using MODIS land surface temperatures and the Crocus snow model to understand the warm bias of ERA-Interim reanalyses at the surface in Antarctica', Cryosphere, 8: 1361-73.

- ***Line 244: What does AMPS stand for? It should be defined before the first use..***

Response:

Thank you for the Reviewer's comments. AMPS stands for the Antarctic Mesoscale Prediction System (details available at https://www2.mmm.ucar.edu/rt/amps/). We have included the definition of AMPS before its first use.

Revision in the manuscript:

We have added

"and the integration of MPAS into Antarctic Mesoscale Prediction System (AMPS) has been planned"

in the revised manuscript (lines 40-41, page 2).

- ***Line 245: Interesting point. What is the potential effect of this missing process on temperature bias in Noah MP?***

Response:

Thank you for the reviewer's question. We agree to discuss the potential effect of this missing process on temperature bias in Noah parameterization. The Noah Land Surface Model (LSM) omits the sublimation process from blowing snow; consequently, the cooling effect of sublimation may be neglected, leading to an overestimation of model temperature during blowing snow caused by strong winds. Interestingly, our analysis indeed reveals that the warm bias in iAMAS slightly increases with higher wind speeds (see Fig. R2 in this Response letter). When comparing iAMAS simulations with measurements from all Automatic Weather Stations (AWS) in Antarctica, statistics show that a 10 m/s increase in measured wind speed corresponds to a 0.5 K rise in the temperature difference for iAMAS minus AWS.

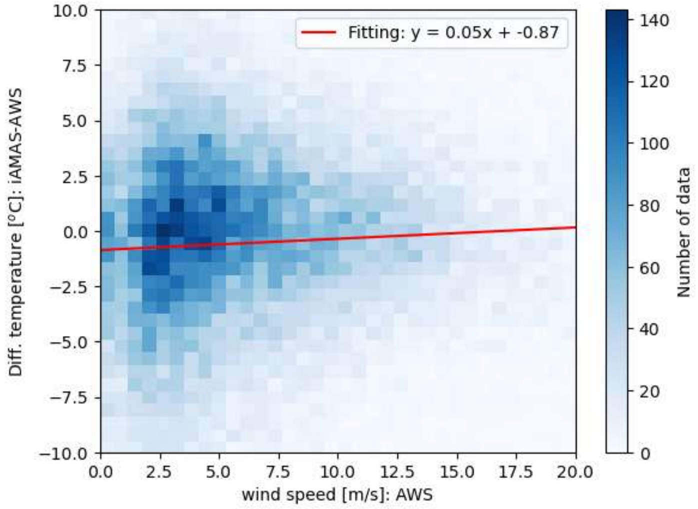

Figure R2. Histogram for wind speed observed AWS and temperature difference for iAMAS-AWS

Revision in the manuscript:

We have added

"Wille et al. (2016) indicated that the Noah Land Surface Model (Noah LSM), used by iAMAS in this study, omits the sublimation process from blowing snow. Consequently, the cooling effect of sublimation may be neglected, potentially leading to an overestimation of temperature in the model during blowing snow events driven by strong winds. Interestingly, our analysis reveals that the warm bias in iAMAS slightly increases with higher wind speeds. When comparing iAMAS simulations with measurements from all AWS in Antarctica, the statistics show that a 10 m s^{-1} increase in measured wind speed corresponds to a 0.5 K rise in the temperature difference between iAMAS and AWS."

in the revised manuscript (lines 218-223, page 10).

References:

Wille, J. D., Bromwich, D. H., Nigro, M. A., Cassano, J. J., Mateling, M., Lazzara, M. A., and Wang, S.-H.: Evaluation of the AMPS Boundary Layer Simulations on the

Ross Ice Shelf with Tower Observations, Journal of Applied Meteorology and Climatology, 55, 2349 615 – 2367, https://doi.org/10.1175/JAMC-D-16-0032.1, 2016

- ***Line 300: the unit is probably wrong here. Should it be K/km instead of K/m?***

Response:

Thank you for the Reviewer's careful check. The correct unit is K/km rather than K/m; we apologize for the typographical error.

Revision in the manuscript:

We have replaced
"The results for April indicate that U120km (22 K m^{-1}) exhibits stronger temperature inversions compared to radiosonde measurements (3 K m^{-1})"
with
"The results for April indicate that U120km (22.1 K km^{-1}) exhibits stronger temperature inversions compared to radiosonde measurements (2.9 K km^{-1})."
in the revised manuscript (lines 348-3450, page 18).

RC2: Anonymous Referee #2, 07 Apr 2025

General Comments:

This is an interesting manuscript that investigates the performance of the MPAS model (see below) over Antarctica in relation to in-situ observations and the ERA5 global reanalysis. The sensitivity of the model results to the model grid spacing is emphasized, and the results are in line with expectations. It is to my knowledge the first manuscript describing the performance of MPAS over Antarctica in the refereed literature. However, there are many aspects to the manuscript that need major improvement to reflect reality.

Response:

We thank the Reviewer for providing us very detailed and useful comments, which have been instrumental in enhancing the quality and clarity of our manuscript. We have carefully considered all the comments and have made comprehensive revisions to address each point raised. Our detailed responses to the Reviewers' comments are provided below.

- ***First, the iAMAS model that is run here without the chemistry component activated is actually the MPAS model available from NCAR. After looking at Gu et al. (2022), the changes (apart from the atmospheric chemistry component) are focused on efficient execution on an HPC platform. The atmospheric physics options used here are those available with MPAS (https://mpas-dev.github.io/atmosphere/atmosphere.html) that originate from various versions of WRF.***

Response:

We appreciate the reviewer’s comments. We have chosen to name our atmospheric model "iAMAS" for three primary reasons: (1) iAMAS adopts the dynamic core of the Model for Prediction Across Scales (MPAS), and we have acknowledged this significant contribution in the manuscript. (2) As indicated in the manuscript, iAMAS incorporates several coding optimizations, including multi-dimensional parallelism, aggressive and fine-grained optimization, manual vectorization, and parallelized I/O fragmentation up on the many-core heterogeneous-architecture of the China Sunway HPC platform, which is incompatible with MPAS anymore. The evaluation of this specific model lays the foundation of our future research. (3) iAMAS will be employed in future studies to explore the impact of human activities (particularly aerosol feedbacks) on the polar regions and mid-latitudes. Using the model name "iAMAS" for the evaluation studies to ensure consistency across those research efforts in future.

Since the iAMAS used in our experiments shares similar dynamics and physics with MPAS, comparable results may also be expected for MPAS (v7.0) and later versions.

Revision in the manuscript:

We have added

"Since the iAMAS used in our experiments uses similar dynamics and physical process with MPAS (V7.0), comparable results may also be expected for MPAS (v7.0)."

in the revised manuscript (lines 72-74, page 3).

- ***Second, the manuscript needs to consider the Antarctic Mesoscale Prediction System (AMPS) much more carefully than is done. AMPS has been run routinely for many years, starting with MM5 before moving on to the current WRF model. Here is the best reference: doi: 10.1175/BAMS-D-11-00186.1. It is run on a polar stereographic projection, i.e., no pole point problem, with the finest grid around Ross Island currently being 0.89 km grid spacing. In addition, AMPS has been running MPAS for a number of years, although this is not well known and unfortunately there is no peer reviewed manuscript. However, the following conference presentation should be referred to and discussed to provide a quantitative context for your results. https://amrc.ssec.wisc.edu/presentations_2017/Day1/powers_mpas.pdf. More recent summaries of the status of MPAS in AMPS are provided here: https://polarmet.osu.edu/WAMC_2024/pdf/WAMC_2.08.pdf and https://polarmet.osu.edu/WAMC_2024/pdf/WAMC_2.09.pdf***

Response:

We appreciate the reviewer's comment and agree that regional simulations (such as AMPS) do not suffer from the pole point problem. In the original manuscript, discussing the global and regional models together may lead to confusion or misinterpretation. We intended to convey that the WRF is hard to perform global simulations due to the pole problem—this limitation, often referred to as its "limited-area capability" (Powers and Manning, 2017). Consequently, the WRF model generally performs regional simulations and requires boundary conditions for its calculations (e.g., Powers et al., 2012). We will revise our expression accordingly in the updated manuscript.

We also thank the reviewer for sharing the conference presentations (Powers and Manning 2017) on MPAS simulations in Antarctica. These materials are valuable for analyzing the results presented in our manuscript. We agree to reference these presentations and provide a quantitative context for our findings. Powers and Manning (2017) demonstrate that the performance of both WRF and MPAS declines during the colder months (July-August), which aligns with our results. For instance, in East Antarctica, the simulations from Powers and Manning (2017) show that the temperature RMSE for WRF (MPAS) is 2.73 °C (2.14 °C) in summer and 5.08 °C (7.24 °C) in winter. Additionally, Powers and Manning (2017) further observe that wind speed simulations exhibit a similar performance decline in winter, with the near-surface wind speed RMSE in East Antarctica for WRF (MPAS) being 1.45 m s^{-1} (1.41 m s^{-1}) for December-January and 2.49 m s^{-1} (1.93 m s^{-1}) for July-August.

Two recent summaries on the status of MPAS in AMPS (Manning and Powers, 2024a; 2024b), introduced by the reviewer, are highly relevant to our work. We plan to incorporate them into the Introduction in the revised manuscript to provide readers with a more comprehensive understanding of the current state of Antarctic simulation research. Manning and Powers (2024a; 2024b) and our team think alike, recognizing the shortcomings of structured meshes and the issues with polar singularities. Manning and Powers (2024a; 2024b) also conduct research on Antarctic simulation using unstructured meshes, based on the MPAS (Model for Prediction Across Scales), and the integration of MPAS into AMPS has been planned.

Revision in the manuscript:

We have replaced

"the iAMAS model (particularly at coarse grid resolutions like 120 km) exhibits a cold bias and stronger wind speeds, consistent with biases identified in other Antarctic simulations using regional models with latitude-longitude grids."

with

"the iAMAS model (particularly at coarse grid resolutions like 120 km) exhibits a cold bias and stronger wind speeds, consistent with biases identified in other Antarctic simulations using regional models."

in the revised manuscript (lines 12-14, page 1).

We have replaced

"Then the regular latitude-longitude grid is the most commonly used configuration in regional atmospheric models (e.g., the Weather Research and Forecasting (WRF) Model; Skamarock et al., 2008). As for global model, the application of unstructured meshes (e.g., Voronoi meshes; Skamarock et al., 2012) was proposed as a method to avoid polar singularities."

with

"To avoid polar singularities, global simulations have adopted alternative grid systems such as cubed-sphere grids (e.g., The GFDL Finite-Volume Cubed-Sphere Dynamical Core (FV3); Putman and Lin, 2007; Harris and Lin, 2013) and Spherical Centroidal Voronoi Tessellations (SCVT) meshes (Ringler et al., 2010; Skamarock et al., 2012; Thuburn et al., 2009)."

in the revised manuscript (lines 30-33, page 2).

We have added

"Table 3 shows that the performance of iAMAS declines during the colder months (April and July). This is consistent with the Antarctic simulation results presented by Powers and Manning (2017), who found that the temperature RMSE for WRF(MPAS) is 2.73 °C (2.14 °C) in December-January and 5.08 °C (7.24 °C) in July-August."

in the revised manuscript (lines 229-231, page 11).

We have added

"Table 6 shows that the wind speed performance of iAMAS declines during the colder months (April and July). Powers and Manning (2017) also observed that wind speed simulations exhibit a similar performance decline in Antarctic winter, with the near-surface wind speed RMSE in East Antarctica for WRF (MPAS) being 1.45 m s^{-1} (1.41 m s^{-1}) for December-January and 2.49 m s^{-1} (1.93 m s^{-1}) for July-August."

in the revised manuscript (lines 304-307, page 17).

We have added

"Manning and Powers (2024a; 2024b) also conduct research on Antarctic simulation using SCVT meshes, based on the Model for Prediction Across Scales (MPAS), and the integration of MPAS into Antarctic Mesoscale Prediction System (AMPS) has been planned."

in the revised manuscript (lines 39-41, page 2).

We have replaced

"To our knowledge, this is the first instance of an explicit evaluation of a global unstructured mesh over the Antarctic, as previous studies of Antarctic simulations have predominantly utilized regional model with regular latitude-longitude grids."

with

"This study serves as a valuable reference for implementing Antarctic simulations using a global model with an unstructured SCVT mesh."

in the revised manuscript (lines 480-481, page 27).

References:

Harris, L. M. and Lin, S.-J.: A Two-Way Nested Global-Regional Dynamical Core on the Cubed-Sphere Grid, Monthly Weather Review, 141, 283 – 306, https://doi.org/10.1175/MWR-D-11-00201.1, 2013

Manning, Kevin W. and Powers, Jordan G. 2024a. AMPS update – June 2024. NSF National Center for Atmospheric Research, Mesoscale and Microscale Meteorology Laboratory. 19th workshop on Antarctic meteorology and climate: June 2024. Columbus, Ohio, USA. https://polarmet.osu.edu/WAMC_2024/pdf/WAMC_2.08.pdf, last accessed: 2025-04-13, 2025

Manning, Kevin W. and Powers, Jordan G., 2024b. AMPS: future plans. Mesoscale and Microscale Meteorology Laboratory, National Center for Atmospheric Research. Workshop on Antarctic meteorology and climate: June 2024. Boulder, Colorado, USA, https://polarmet.osu.edu/WAMC_2024/pdf/WAMC_2.09.pdf, last accessed: 2025-04-13, 2025

Putman, W. M. and Lin, S.-J.: Finite-volume transport on various cubed-sphere grids, Journal of Computational Physics, 227, 55–78, https://doi.org/https://doi.org/10.1016/j.jcp.2007.07.022, 2007

Powers, J. G., K. W. Manning, D. H. Bromwich, J. J. Cassano, and A. M. Cayette, 2012: A Decade of Antarctic Science Support Through Amps. Bull. Amer. Meteor. Soc., 93, 1699–1712, https://doi.org/10.1175/BAMS-D-11-00186.1.

Powers, Jordan G. and Manning, Kevin W. 2017. Assessment of the Model for Prediction Across Scales (MPAS) in AMPS. Mesoscale and Microscale Meteorology Laboratory, National Center for Atmospheric Research. Boulder, CO. https://amrc.ssec.wisc.edu/presentations_2017/Day1/powers_mpas.pdf, last accessed: 2025-04-13, 2025

Ringler, T. D., Thuburn, J., Klemp, J. B., and Skamarock, W. C.: A unified approach to energy conservation and potential vorticity dynamics for arbitrarily-structured C-grids, Journal of Computational Physics, 229, 3065–3090, https://doi.org/10.1016/j.jcp.2009.12.007, 2010

Skamarock, W. C., Klemp, J. B., Dudhia, J., Gill, D. O., Barker, D., Duda, M. G., . . . , and Powers, J. G.: A Description of the Advanced Research WRF Version 3 (No. NCAR/TN-475+STR), Report, University Corporation for Atmospheric Research, https://doi.org/10.5065/D68S4MVH, 2008

Skamarock, W. C., Klemp, J. B., Duda, M. G., Fowler, L. D., Park, S.-H., and Ringler, T. D.: A Multiscale Nonhydrostatic Atmospheric Model Using Centroidal Voronoi Tesselations and C-Grid Staggering, Monthly Weather Review, 140, 3090–3105, https://doi.org/10.1175/mwr-d-11-00215.1, 2012

Thuburn, J., Ringler, T. D., Skamarock, W. C., and Klemp, J. B.: Numerical representation of geostrophic modes on arbitrarily structured C-grids, Journal of Computational Physics, 228, 8321–8335, https://doi.org/https://doi.org/10.1016/j.jcp.2009.08.006, 2009

- ***Third, the polar version of WRF (PWRF) has been extensively used over and validated for Antarctica. The most recent peer reviewed publication is https://doi.org/10.1007/s11707-022-0971-8 that considers a full annual cycle and considers both surface and upper air observations. PWRF with a few modifications is used in AMPS. The extensive PWRF literature provides guidance on the Antarctic performance of available physics options in WRF. You should quantitatively contrast your results with those presented by Xue et al. in the above reference.***

Response:

We appreciate the reviewer's suggestion and agree to quantitatively compare our results with those presented by Xue et al. (2022), as their studies also focus on Antarctic simulations. Xue et al. (2022) used the "forecast mode" of Polar WRF 4.1.1, with an improved NoahMP Land Surface Model (LSM), to perform 2-meter temperature simulations over the entire Antarctic region.

Both Polar WRF and iAMAS employed some physics options (e.g., Noah LSM) in WRF. As Xue et al. (2022) indicated, modifying the albedo to 0.8 removed the strong warm bias, resulting in the best performance during the summer. Then one may expect that the warm bias in the 2-m temperature shown in Fig. 3 in the revised manuscript for January may be due to the relatively low snow albedo (0.55 in the default setting by iAMAS).

In addition, some results from Xue et al. (2022) are consistent with our findings, particularly regarding the performance drop-off of iAMAS during colder months (April and July). Xue et al. (2022) report that the RMSE for 2-meter temperature is higher in July-August (4.03°C) than in December-February (3.06°C). Regarding lateral boundary data for the atmospheric model, results from ERA5 (see Table 3 in the revised manuscript) and ERA-Interim (see Xue et al. 2022) both indicate that the 2-meter temperature RMSE is larger in July than in January. Thus, one may infer that the 2-meter temperature errors in the atmospheric model could be influenced, at least in part, by its lateral boundary conditions (ERA5 or ERA-Interim).

Regarding wind speed, a similar performance drop-off during colder months is also observed. Xue et al. (2022) show that the RMSE for 10-meter wind speed is higher in July-August (4.20 m s^{-1}) than in December-February (3.20 m s^{-1}). Regarding lateral boundary conditions for the atmospheric model, results from ERA5 (see Table 6 in this study) and ERA-Interim (see Xue et al. 2022) both indicate that the near-surface wind speed RMSE is larger in July than in January. Thus, one may infer that the near-surface wind speed errors in the atmospheric model (iAMAS or Polar WRF) could be partly influenced by its lateral boundary data (ERA5 or ERA-Interim).

Fig. 8 in the revised manuscript shows that the temperature bias is large at both the bottom and top levels. Xue et al. (2022) demonstrated similar results. For example, in July, the bias (Model-Observation) is -0.85°C and 0.11°C at 975 hPa and 100 hPa (Xue et al. 2022), respectively, but is only 0.04°C at 600 hPa. The temperature profiles in Xue et al. (2022) show that temperatures are relatively more variable at the bottom and top levels, with a larger temperature spread near the surface and at the top.

Revision in the manuscript:

We have replaced

"Comparison of iAMAS with ERA5 in Fig. 3 reveals that all four iAMAS experiments at various resolutions generally simulate warmer temperatures than ERA5 in January, but show colder temperatures in April and July."

with

"Comparison of iAMAS with ERA5 in Fig. 3 reveals that all four iAMAS experiments, at various resolutions, generally simulate warmer temperatures than ERA5 in January. This warm bias may be attributed to the relatively low snow albedo value of 0.55 used in the iAMAS model. According to Xue et al. (2022), increasing the albedo to 0.8 effectively removed the strong warm bias and resulted in improved performance during austral summer. In April and July, iAMAS simulations exhibit colder temperatures than ERA5."

in the revised manuscript (lines 198-202, page 9).

We have added

"Table 3 shows that the performance of iAMAS declines during the colder months (April and July). This is consistent with the Antarctic simulation results presented by Powers and Manning (2017), who found that the temperature RMSE for WRF (MPAS) is 2.73 °C (2.14 °C) in December-January and 5.08 °C (7.24 °C) in July-August. Additionally, Xue et al. (2022) conducted Polar WRF simulations and reported that the RMSE for 2-meter temperature is higher in July–August (4.03 °C) than in December–February (3.06 °C). Results from ERA5 (see Table 3 in this study) and ERA-Interim (see Xue et al., 2022) both indicate that the 2-m temperature RMSE is larger in July than in January. Thus, it can be inferred that 2-m temperature errors in the atmospheric model may be influenced, at least in part, by its lateral boundary conditions (ERA5 or ERA-Interim)"

in the revised manuscript (lines 229-235, page 11).

We have added

"Table 6 shows that the wind speed performance of iAMAS declines during the colder months (April and July). Powers and Manning (2017) also observed that wind speed simulations exhibit a similar performance decline in Antarctic winter, with the near-surface wind speed RMSE in East Antarctica for WRF (MPAS) being 1.45 m s^{-1} (1.41 m s^{-1}) for December-January and 2.49 m s^{-1} (1.93 m s^{-1}) for July-August. In addition, Xue et al. (2022) conducted Polar WRF simulations and reported that the RMSE for 10-m wind speed is higher in July–August (4.20 m s^{-1}) than in December–February (3.20 m s^{-1}). Reanalysis data are typically used as lateral boundary conditions for atmospheric models. Four reanalyses (ERA5, ERA-Interim, CFSR, and MERRA-2) consistently show degraded performance in reconstructing near-surface wind speeds during the Antarctic winter compared to summer (see Table 6 in this study; Xue et al., 2022; Gossart et al., 2019). These findings suggest that errors in near-surface wind

speed simulations using both iAMAS and WRF may be partially attributed to deficiencies in their reanalysis-based boundary conditions."
in the revised manuscript (lines 304-313, page 17).

We have added
"Fig. 8 shows that the higher temperature biases are pronounced at both the lower and upper atmospheric levels. Xue et al. (2022) reported similar findings; for example, in July, they found that the temperature bias (Polar WRF–Observation) is -0.85 °C at 975 hPa and 0.11 °C at 100 hPa, while it is only 0.04 °C at 600 hPa. Their results indicate that temperature variability is greater near the surface and upper levels, with a broader temperature spread observed in these regions."
in the revised manuscript (lines 368-371, page 20).

References:

Xue, J., Xiao, Z., Bromwich, D.H. et al. Polar WRF V4.1.1 simulation and evaluation for the Antarctic and Southern Ocean. Front. Earth Sci. 16, 1005–1024 (2022). https://doi.org/10.1007/s11707-022-0971-8

- ***Fourth, a lot is known about ERA5 performance in the Antarctic, yet none is referenced here. Here is a good reference to consult and incorporate into this manuscript. https://doi.org/10.1175/JCLI-D-19-0030.1***

Response:

We appreciate the reviewer's suggestions and agree to include the reference to ERA5 (Gossart et al., 2019) in our revised manuscript. This will help provide a more comprehensive analysis of ERA5 performance. Gossart et al. (2019) show that three reanalysis (ERA5, ERA-Interim, and CFSR) exhibit a substantial warm bias over the interior, especially during the winter season, which is consistent with the results in Fig. 3 of the revised manuscript. Furthermore, Gossart et al. (2019) show that ERA5 overall captures near-surface temperature in Antarctica more accurately than other reanalyses (ERA-Interim, CFSR, and MERRA-2).

The performance of four reanalysis (ERA5, ERA-Interim, CFSR, and MERRA-2) in wind speed decreases during winter when katabatic forcing is dominant (Gossart et al., 2019). This is consistent with the results in this study, where ERA5 shows a significant increase in 3 m wind speed RMSE in April and July, as shown in Table 6.

Revision in the manuscript:

We have added
"Similarly, Gossart et al. (2019) reported that three reanalyses (ERA5, ERA-Interim, and CFSR) exhibit substantial warm biases over the Antarctic interior, particularly during winter."

in the revised manuscript (lines 195-197, page 9).

We have added

"Four reanalyses (ERA5, ERA-Interim, CFSR, and MERRA-2) consistently show degraded performance in reconstructing near-surface wind speeds during the Antarctic winter compared to summer (see Table 6 in this study; Xue et al., 2022; Gossart et al., 2019). These findings suggest that errors in near-surface wind speed simulations using iAMAS and WRF may be partially attributed to deficiencies in their reanalysis-based boundary conditions."

in the revised manuscript (lines 309-313, page 17).

References:

Gossart, A., S. Helsen, J. T. M. Lenaerts, S. V. Broucke, N. P. M. van Lipzig, and N. Souverijns, 2019: An Evaluation of Surface Climatology in State-of-the-Art Reanalyses over the Antarctic Ice Sheet. J. Climate, 32, 6899–6915, https://doi.org/10.1175/JCLI-D-19-0030.1.

- ***Fifth, we checked one day of data for ERA5 for the average wind speed at 89.5, 89.75, and 90°S (from the square root (u2 + v2)) from 600 hPa and above. The first two values were close in magnitude (3-12 m/s) while the value at the pole point was nearly zero. We also checked at the North Pole and found the same problem. Thus, the pole problem in ERA5 for wind speed reported here is supported.***

Response:

We appreciate the reviewer's careful review and further comments (https://doi.org/10.5194/gmd-2024-229-RC3) regarding the issue of low wind speeds at the South Pole (90°S). We would like to note that the pole problem for wind speed is also supported by ERA5 Climate Data Store (CDS) data. In the revised manuscript, we will clarify the issue of low wind speeds at the South Pole using a more official explanation from the ERA5 CDS. This wind speed issue arises from the method by which winds are derived from vorticity and divergence in spherical harmonic representation when interpolated onto a regular grid in the Climate Data Store. As a result, winds at neighboring locations, such as 89.75°S, are used instead of 90°S, because the interpolation at 89.75°S is unaffected and remains normal.

Revision in the manuscript:

We have replaced

"Initially, ERA5 data at SP were extracted from a latitude of 90°S. We found that ERA5 wind speeds are significantly lower than radiosonde measurements (see red circles in Fig. 11). This discrepancy suggests that the ERA5 data may be affected by polar singularity issues, possibly due to the limitations of vector interpolation at the polar grid center (to be discussed later). Subsequently, data from grid points at a latitude of

89.75°S were obtained. We found that the ERA5 wind speeds at 89.75°S are reasonable and do not exhibit the significant underestimation of wind speed, as indicated by the blue crosses in Fig. 11.

Concerning the 3-m wind speed (Sect. 3.1.4), the ERA5 data at SP do not exhibit significant underestimation when compared to AWS measurements. This is because the two AWS sites (HEN: 89.02°S, 1.03°W; NIC: 89.00°S, 89.67°W) at SP are not located exactly at the polar grid center (90°S), thereby avoiding the polar singularity problem. Furthermore, the analysis of ERA5 surface-layer (10-m) wind speeds at a latitude of 90°S also indicates significant underestimation (not shown), consistent with the polar singularity issues identified in upper-air wind of ERA5 data.

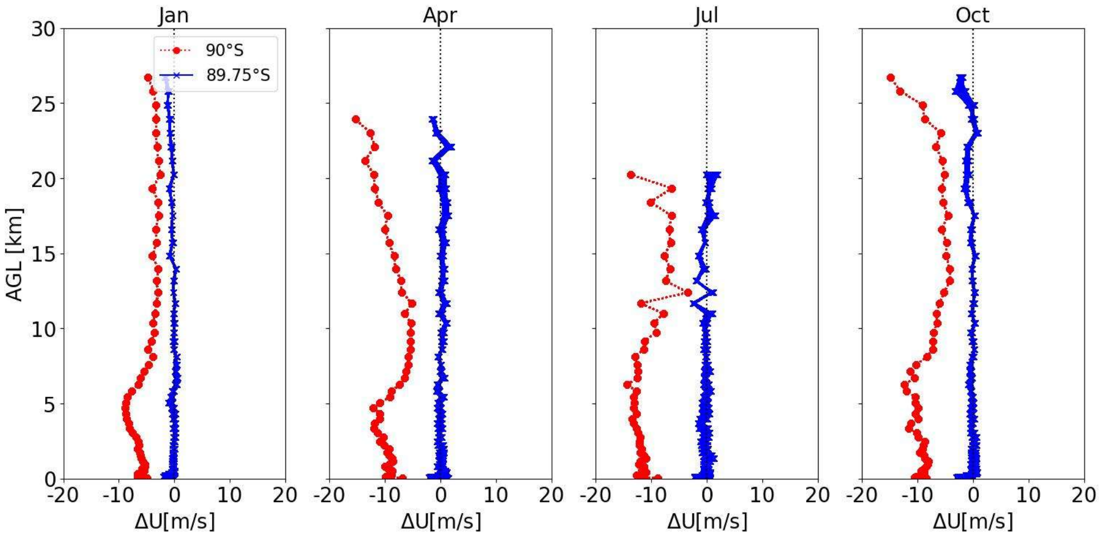

Figure 11. Monthly median values of wind speed biases (ΔU [m/s]) for ERA5 minus radiosondes. Red dots and blue crosses represent the results for 90°S and 89.75°S, respectively. Data are displayed for all longitudes (180°W to 180°E) at both 90°S and 89.75°S. The data for each longitude at 90°S are identical with overlapped points. While the results at 89.75°S exhibit slight differences across longitudes.

Given that the ERA5 wind speed at a latitude of 90°S appears less reliable, then the wind speed at the ERA5 grid point with coordinates 89.75°S, 0°E is utilized. The biases for the wind speed profile are displayed in Fig. 12. The wind speed bias for ERA5 is generally below 1 m s^{-1} in a large part of the atmosphere (see the second column in Fig. 12). The wind speed simulated by all four iAMAS experiments with various resolutions at SP seems unaffected by the ERA5 initialized field at 90°S and yield generally reasonable results. This may be attributed to the limited influence of a single grid point (i.e., the point at 90°S, -°E) on the iAMAS simulations.

Interestingly, we found that the iAMAS simulations can replicate the unrealistically low wind speed values at 90°S after interpolating the iAMAS unstructured mesh to a regular latitude-longitude grid using the Earth System Modeling Framework (ESMF Balaji et al., 2024). Similarly, the ERA5 latitude-longitude grid data are interpolated from a Gaussian grid (Hersbach et al., 2020; Hortal and Simmons, 1991). We argue that the interpolation algorithm for ERA5 wind speeds (specifically, the Uand V-components) is unreliable at the polar grid center at 90°S, as the definition of wind direction becomes inapplicable here. In contrast to wind vectors, scalar quantities do not encounter this directional issue, which explains why temperature, pressure, and specific humidity in ERA5 do not exhibit this polar singularity problems."

with

"ERA5 data for wind speed exhibit polar singularity issues. According to the ERA5 Climate Data Store (CDS: https://confluence.ecmwf.int/pages/viewpage.action?pageId=129134800), at the poles (i.e., at 90°N and 90°S), the U and V components of the wind are significantly underestimated. This problem arises from the way winds are derived from vorticity and divergence in spherical harmonics representation (the native model format) when interpolated onto a regular latitude-longitude grid in the CDS. Currently, it is not anticipated that this issue will be resolved. As recommended by the ERA5 CDS, data from grid points at a latitude of 89.75°S are used to represent the wind speed at the SP to avoid the polar singularity issues.

Concerning the 3-m wind speed (Sect. 3.1.4), the ERA5 data at the SP do not exhibit significant underestimation when compared to AWS measurements. This is because the two AWS sites (HEN: 89.02°S, 1.03°W; NIC: 89.00°S, 89.67°W) at the South Pole are not located exactly at the polar grid center (90°S), thereby avoiding the polar singularity problem.

The biases for the wind speed profile are displayed in Fig. 11. The wind speed bias for ERA5 is generally below 1 m s^{-1} across a large portion of the atmosphere (see the second column in Fig. 11). The wind speed simulated by all four iAMAS experiments with various resolutions at the SP seems unaffected by the ERA5 initialized field at 90°S and yields overall reasonable results. This may be attributed to the limited influence of a single grid point (i.e., the point at 90°S, -°E) on the iAMAS simulations."

in the revised manuscript (lines 442-455, page 25).

- ***Specific Comments:***

  Line 155: The scheduled frequency of radiosonde launches at McMurdo and South Pole varies during the year with generally 1 per day during the colder months.

Response:

We appreciate the reviewer's comments and will include a description, indicating that the scheduled frequency of radiosonde launches at McMurdo and the South Pole is generally once per day during the colder months. By the way, we have checked the radiosonde measurements at both locations and found that radiosondes are typically launched once a day during the colder months, usually at 00:00 UTC.

Revision in the manuscript:

We have replaced

"Radiosounding at MM and SP is conducted twice daily at 00:00 and 12:00 UTC, while at DC, it launched once daily at 12:00 UTC."

with

"Radiosonde launches at MM and the SP were generally conducted twice daily at 00:00 and 12:00 UTC during the warmer months, and once daily—typically at 00:00 UTC—during the colder months. At DC, radiosondes were generally launched once daily at 12:00 UTC throughout the year."

in the revised manuscript (lines 164-166, page 8).

- ***Lines 169-171: What roughness length did you use in the logarithmic wind profile to adjust the 10 m wind speeds down to 3 m?***

Response:

The roughness length used in the logarithmic wind profile to adjust the 10 m wind speeds to 3 m is 0.001 m. This value is consistent with observations (Chamberlain, 1983) and previous model settings (Bromwich et al., 2013). In the revised manuscript, we will clarify that the 10 m wind speeds were adjusted to 3 m using the logarithmic wind profile with a roughness length of 0.001 m.

Revision in the manuscript:

We have replaced

"For wind speed, the 10-m wind speeds from both iAMAS and ERA5 are adjusted using the logarithmic wind profile down to 3 m above the model surface to correspond more closely to the AWS wind measurements."

with

"For wind speed, the 10-m wind speeds from both iAMAS and ERA5 are adjusted to 3 m above the model surface using a logarithmic wind profile with a roughness length of 0.001 m, to closely match the height of AWS wind measurements."

in the revised manuscript (lines 185-187, page 9).

References:

Chamberlain, A.C. Roughness length of sea, sand, and snow. Boundary-Layer Meteorol 25, 405–409 (1983). https://doi.org/10.1007/BF02041157

Bromwich, D. H., F. O. Otieno, K. M. Hines, K. W. Manning, and E. Shilo (2013), Comprehensive evaluation of polar weather research and forecasting model performance in the Antarctic, J. Geophys. Res. Atmos., 118, 274–292, doi:10.1029/2012JD018139.

- ***Figure 3 for January: It looks like there is a problem with the snow albedo used in iAMAS for interior Antarctica. It should be no smaller than 0.8. Otherwise, large warm biases in the 2-m temperature will be simulated. See Xue et al. (2022).***

Response:

We appreciate the reviewer's suggestions and will add a discussion in the revised manuscript, noting that the warm bias in the 2-m temperature shown in Fig. 3 for January may be due to the relatively low snow albedo (0.55 in the default setting by iAMAS). As Xue et al. (2022) indicated, modifying the albedo to 0.8 removed the strong warm bias, resulting in the best performance during the summer.

Revision in the manuscript:

We have replaced

"Comparison of iAMAS with ERA5 in Fig. 3 reveals that all four iAMAS experiments at various resolutions generally simulate warmer temperatures than ERA5 in January"

with

"Comparison of iAMAS with ERA5 in Fig. 3 reveals that all four iAMAS experiments, at various resolutions, generally simulate warmer temperatures than ERA5 in January. This warm bias may be attributed to the relatively low snow albedo value of 0.55 used in the iAMAS model. According to Xue et al. (2022), increasing the albedo to 0.8 effectively removed the strong warm bias and resulted in improved performance during austral summer."

in the revised manuscript (lines 198-202, page 9).

References:

Xue, J., Xiao, Z., Bromwich, D.H. et al. Polar WRF V4.1.1 simulation and evaluation for the Antarctic and Southern Ocean. Front. Earth Sci. 16, 1005–1024 (2022). https://doi.org/10.1007/s11707-022-0971-8

- ***Lines 188-190: This discussion refers to the ERA-Interim reanalysis and not ERA5.***

Response:

We appreciate the reviewer's careful review and will make it clear in our manuscript that this refers to the ERA-Interim reanalysis.

Revision in the manuscript:

We have replaced

"Fréville et al. (2014) also identified a widespread overestimation of temperature in ERA reanalysis data when compared to Moderate Resolution Imaging Spectroradiometer (MODIS) data in the Antarctic, they argue that this warm bias may result from an overestimation of surface turbulent fluxes under very stable conditions."

with

"Fréville et al. (2014) also identified a widespread overestimation of temperature in ERA-Interim reanalysis data when compared to Moderate Resolution Imaging Spectroradiometer (MODIS) data in the Antarctic, they argue that this warm bias may result from an overestimation of surface turbulent fluxes under very stable conditions."

in the revised manuscript (lines 208-210, pages 9).

- ***Table 3: The 2-m air temperature results one gets depends a lot on the land surface model. How did you initialize the Noah LSM?***

Response:

We appreciate the reviewer's questions. The Noah LSM is initialized by ERA5 reanalysis, ERA5 provided sea-surface temperature, snow depth, 2-meter temperature, etc. The original manuscript already pointed it out that iAMAS is initialized using ERA5. In the iAMAS itself, there are three TBL files (VEGPARM.TBL, SOILPARM.TBL, and GENPARM.TBL) used to initialize the Noah LSM. Our version of the Noah LSM originates from WRF version 4.0.3. For more information on these three TBL files, please refer to the following links:

https://github.com/wrf-model/WRF/blob/release-v4.0.3/run/VEGPARM.TBL

https://github.com/wrf-model/WRF/blob/release-v4.0.3/run/SOILPARM.TBL

https://github.com/wrf-model/WRF/blob/release-v4.0.3/run/GENPARM.TBL

- ***Table 4: It is very challenging to measure atmospheric moisture content at low air temperatures because of the tiny amounts of water vapor present.***

Response:

We appreciate the reviewer's comments and will add a description in the revised manuscript, highlighting the challenges of measuring atmospheric moisture content at low air temperatures due to the extremely small amounts of water vapor present. Lazzara et al. (2012) also noted that humidity errors increase at low temperatures. This will emphasize the difficulties of such measurements and encourage readers to exercise caution when interpreting specific humidity results.

Revision in the manuscript:

We have added

"It is worth noting that measuring atmospheric moisture content at low air temperatures is challenging due to the extremely small amounts of water vapor present. Lazzara et al. (2012) also noted that humidity measurement errors tend to increase under low-temperature conditions."
in the revised manuscript (lines 276-278, pages 14).

References:

Lazzara, M. A., G. A. Weidner, L. M. Keller, J. E. Thom, and J. J. Cassano, 2012: Antarctic Automatic Weather Station Program: 30 Years of Polar Observation. Bull. Amer. Meteor. Soc., 93, 1519–1537, https://doi.org/10.1175/BAMS-D-11-00015.1.

- ***Line 260 "enhancing the barrier effect of air flowing over it". This language requires change because the barrier effect you are talking about refers to the low-level blocking/barrier effect on air encountering an obstacle causing some or all of the air to blow around rather than over the obstacle.***

Response:

We appreciate the reviewer's careful review and will revise our statement in line 260. It seems that our original statement may have caused some misunderstanding, suggesting that the air flowing over the terrain behaves similarly to airflow in the free atmosphere. To avoid such confusion, we will revise the sentence to: "enhancing the blocking/barrier effect of rough underlying terrain on the near-surface wind field flow."

Revision in the manuscript:

We have replaced
"As grid resolution increases, iAMAS better resolves the complex terrain, enhancing the barrier effect of air flowing over it (similar to Argentini and Mastrantonio, 1994; O'connor and Bromwich, 1988), which subsequently leads to decreased wind speeds in iAMAS simulations."
with
"As grid resolution increases, iAMAS better resolves the complex terrain, enhancing the blocking/barrier effect of rough underlying terrain on the near-surface wind field flow (similar to Argentini and Mastrantonio, 1994; O'Connor and Bromwich, 1988), which subsequently leads to decreased wind speeds in iAMAS simulations."
in the revised manuscript (lines 298-301, page 16).

- ***Line 261: O'Connor. Fix also in the references.***

Response:

We appreciate the reviewer's careful review and will replace "O'connor" with "O'Connor." The references will also be corrected.

Revision in the manuscript:

We have replaced

“ (similar to Argentini and Mastrantonio, 1994; O’connor and Bromwich, 1988)”

with

“(similar to Argentini and Mastrantonio, 1994; O’Connor and Bromwich, 1988)”

in the revised manuscript (line 300, page 16).

Revision in the manuscript:

We have replaced

“O’connor, W. P. and Bromwich, D. H.: Surface airflow around Windless Bight, Ross Island, Antarctica, Quarterly Journal of the Royal Meteorological Society, 114, 917–938, https://api.semanticscholar.org/CorpusID:140173495, 1988.”

with

“O’Connor, W. P. and Bromwich, D. H.: Surface airflow around Windless Bight, Ross Island, Antarctica, Quarterly Journal of the Royal Meteorological Society, 114, 917–938, https://api.semanticscholar.org/CorpusID:140173495, 1988.”

in the revised manuscript (lines 658-659, page 33).

- ***For your comparisons, you should add the numbers of observing stations involved in the comparisons.***

Response:

We appreciate the reviewer’s suggestions and agree to include the number of AWS stations involved in the comparisons in the revised manuscript. The details are as follows:

Figure/Table in the revised manuscript	Parameter	January	April	July	October
Figure 3/Table 3	2 m temperature	45	47	44	51
Figure 5/Table 4	Surface pressure	42	46	44	48
Figure 6/Table 5	2 m specific humidity	32	34	35	35
Figure 7/Table 6	3 m wind speed	41	42	41	47

Revision in the manuscript:

We have added

“Number of stations: 45 (January), 47 (April), 44 (July), and 51 (October).”

in the revised manuscript (Figure 3 caption, page 10).

We have added

“Number of stations: 45 (January), 47 (April), 44 (July), and 51 (October). ”

in the revised manuscript (Table 3 caption, page 12).

We have added

"Number of stations: 42 (January), 46 (April), 44 (July), 48 (October) ."
in the revised manuscript (Figure 5 caption, page 13).

We have added

"Number of stations: 42 (January), 46 (April), 44 (July), 48 (October)."
in the revised manuscript (Table 4 caption, page 13).

We have added

"Number of stations: 32 (January), 34 (April), 35 (July), 35 (October). "
in the revised manuscript (Figure 6 caption, page 15).

We have added

"Number of stations: 32 (January), 34 (April), 35 (July), 35 (October). "
in the revised manuscript (Table 5 caption, pages 15).

We have added

"Number of stations: 41 (January), 42 (April), 41 (July), 47 (October)."
in the revised manuscript (Figure 7 caption, pages 16).

We have added

"Number of stations: 41 (January), 42 (April), 41 (July), 47 (October)."
in the revised manuscript (Table 6 caption, pages 17).

- ***Figure 8 for October: The model cold biases above ~ 15 km are probably related to the stratospheric ozone treatment in MPAS. ERA5 puts a lot of effort into correctly handling the stratospheric ozone concentration.***

Response:

We appreciate the reviewer's comments and will add a discussion, noting that the cold biases observed above approximately 15 km may be due to insufficient accuracy in handling stratospheric ozone concentration. Since stratospheric ozone during the austral spring over Antarctica has been a significant driver of atmospheric changes in the high southern latitudes in recent decades (Hersbach et al., 2020), while the iAMAS model used in this study does not explicitly consider stratospheric ozone concentrations and their effects on radiation.

Revision in the manuscript:

We have added

"In addition, the cold biases observed above approximately 15 km may also be attributed to the fact that the iAMAS model used in this study does not explicitly consider stratospheric ozone concentrations and their effects on radiation."
in the revised manuscript (lines 365-367, pages 20).

References:

Hersbach H, Bell B, Berrisford P, et al. The ERA5 global reanalysis. Q J R Meteorol Soc. 2020; 146: 1999–2049. https://doi.org/10.1002/qj.3803

- ***Section 3.2.2: Comparisons such as these usually use geopotential height as this variable on constant pressure surfaces is used for atmospheric analysis.***

Response:

We appreciate the reviewer's suggestions and will add a comparison of geopotential height profiles (see Fig. S3). A discussion on the geopotential height profiles will also be included in the revised manuscript. However, the result of the plot and Table will be presented in the supplementary information, instead of the main body of the manuscript, as the original pressure profile results (Fig. 9 in the revised manuscript) are easier to analyze in conjunction with surface pressure.

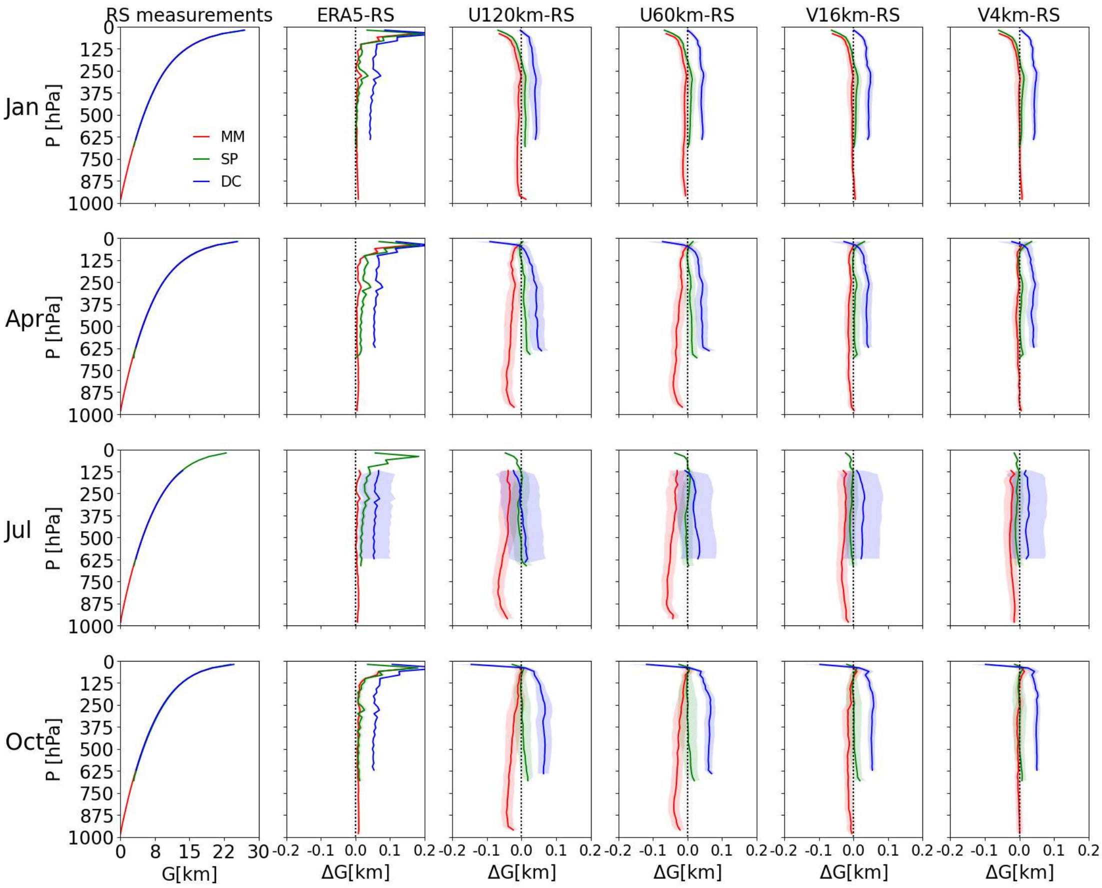

Fig. S3. The first column displays the monthly medians of radiosonde-measured geopotential height (G [km]) profiles. The five rightmost columns show the monthly median geopotential height biases (ΔG [km]) for ERA5 and iAMAS (U120km, U60km, V16km, and V4km) compared to radiosonde measurements. The shading represents the standard error.

Fig. S3 shows that ERA5 displays overall positive geopotential height deviation at all three sites, with a particularly notable deviation at the DC site. The geopotential height biases at MM are overall negative across all months, while the biases at DC are predominantly positive. Table S9 in the revised supplement information presents a statistical evaluation of the 500-hPa geopotential height, which indicates that iAMAS can better simulate the geopotential height in warmer months (e.g., January) than in colder months (e.g., July), similar to the Polar WRF simulations in Antarctica (Xue et al., 2022).

Table S9. Monthly RMSE (BIAS in parentheses) of the 500-hPa geopotential height (m) for ERA5 and iAMAS compared with radiosondes.

Site (Month)	ERA5	U120km	U60km	V16km	V4km
MM (Jan)	5.2 (4.2)	24.1 (-6.7)	21.7 (-7.8)	19.3 (-3.2)	16.9 (-0.4)
MM (Apr)	5.6 (3.6)	49.4 (-31.3)	42.1 (-30.5)	26.2 (-14.8)	24.6 (-7.7)
MM (Jul)	7.3 (3.3)	67.6 (-41.6)	66.7 (-45.5)	53.3 (-26.2)	49.9 (-27.8)
MM (Oct)	7.5 (4.7)	43.8 (-29.0)	44.0 (-26.5)	31.8 (-13.9)	22.4 (-5.4)
SP (Jan)	8.7 (2.0)	28.5 (11.5)	22.9 (8.5)	20.6 (6.7)	20.9 (5.7)
SP (Apr)	17.2 (13.0)	29.7 (13.2)	32.9 (12.5)	33.1 (2.7)	28.2 (1.1)
SP (Jul)	17.1 (14.5)	48.8 (-2.0)	39.9 (-4.6)	32.4 (-8.8)	31.1 (-11.1)
SP (Oct)	15.7 (6.9)	41.2 (6.6)	46.1 (5.7)	34.4 (2.7)	28.9 (0.2)
DC (Jan)	41.3 (41.4)	54.7 (41.9)	48.9 (41.8)	50.4 (44.0)	49.4 (42.9)
DC (Apr)	52.8 (52.4)	68.8 (46.7)	58.2 (43.7)	49.8 (39.3)	51.6 (39.9)
DC (Jul)	97.3 (50.9)	105.3 (12.2)	101.1 (30.9)	103.5 (25.4)	102.0 (20.2)
DC (Oct)	49.9 (49.1)	78.6 (67.6)	66.9 (61.5)	56.5 (52.7)	53.2 (49.9)

Revision in the manuscript:

We have added

"The performance of geopotential height simulations are presented in Fig. S3 and Table S9 of the supplementary information. Fig. S3 shows that ERA5 exhibits overall positive geopotential height deviation at all three sites, with a particularly pronounced deviation at the DC site. At MM, the geopotential height biases are consistently negative across all months except near the model top, while those at DC are predominantly positive. Table S9 presents a statistical evaluation of the 500-hPa geopotential height, indicating that iAMAS performs better in simulating geopotential height during warmer months (e.g., January) than in colder months (e.g., July), which is consistent with the results of Polar WRF simulations over Antarctica reported by Xue et al. (2022)."

in the revised manuscript (lines 412-418, page 22).

We have added

“

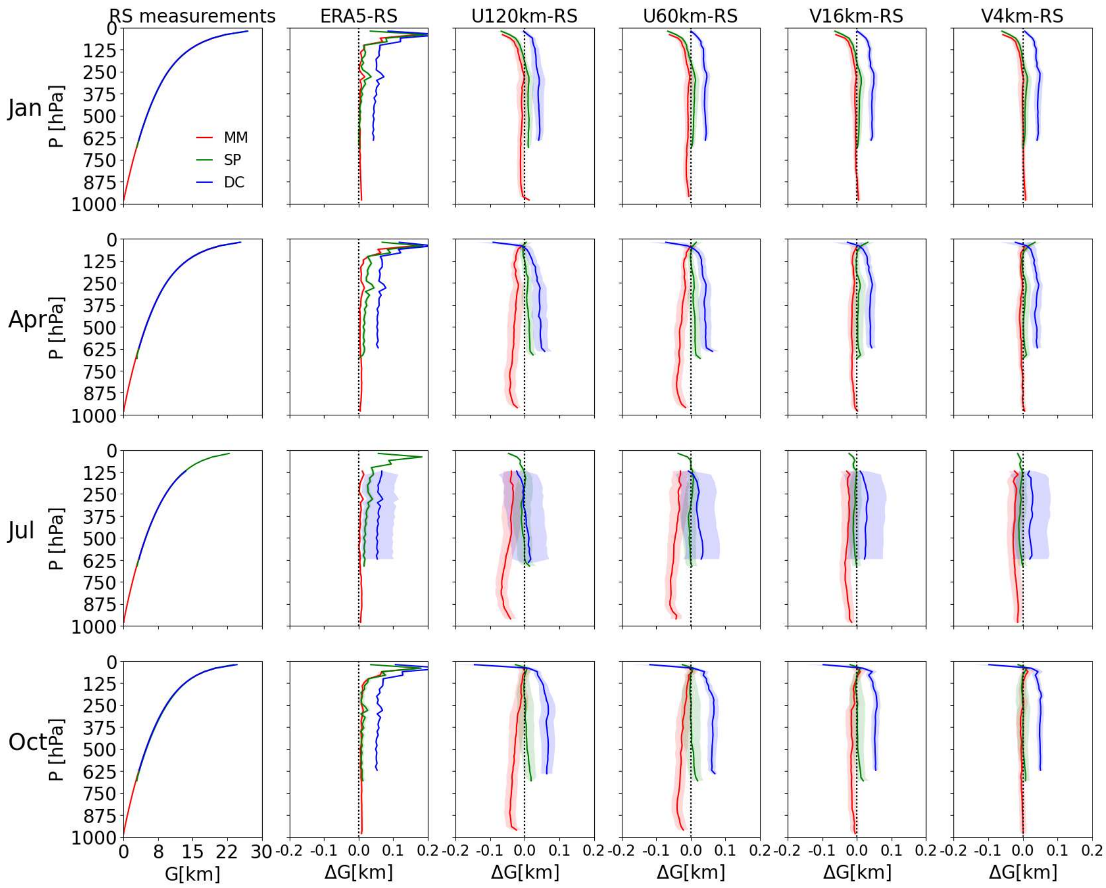

Figure S3. The first column displays the monthly medians of radiosonde-measured geopotential height (G [km]) profiles. The five rightmost columns show the monthly median geopotential height biases (ΔG [km]) for ERA5 and iAMAS (U120km, U60km, V16km, and V4km) compared to radiosonde measurements. The shading represents the standard error.”

in the revised supplement information (Figure S3).

We have added

“

Table S9. Monthly RMSE (BIAS in parentheses) of the 500-hPa geopotential height (m) for ERA5 and iAMAS compared with radiosondes.

Site (Month)	ERA5	U120km	U60km	V16km	V4km
MM (Jan)	5.2 (4.2)	24.1 (-6.7)	21.7 (-7.8)	19.3 (-3.2)	16.9 (-0.4)
MM (Apr)	5.6 (3.6)	49.4 (-31.3)	42.1 (-30.5)	26.2 (-14.8)	24.6 (-7.7)
MM (Jul)	7.3 (3.3)	67.6 (-41.6)	66.7 (-45.5)	53.3 (-26.2)	49.9 (-27.8)
MM (Oct)	7.5 (4.7)	43.8 (-29.0)	44.0 (-26.5)	31.8 (-13.9)	22.4 (-5.4)
SP (Jan)	8.7 (2.0)	28.5 (11.5)	22.9 (8.5)	20.6 (6.7)	20.9 (5.7)
SP (Apr)	17.2 (13.0)	29.7 (13.2)	32.9 (12.5)	33.1 (2.7)	28.2 (1.1)
SP (Jul)	17.1 (14.5)	48.8 (-2.0)	39.9 (-4.6)	32.4 (-8.8)	31.1 (-11.1)

SP (Oct)	15.7 (6.9)	41.2 (6.6)	46.1 (5.7)	34.4 (2.7)	28.9 (0.2)
DC (Jan)	41.3 (41.4)	54.7 (41.9)	48.9 (41.8)	50.4 (44.0)	49.4 (42.9)
DC (Apr)	52.8 (52.4)	68.8 (46.7)	58.2 (43.7)	49.8 (39.3)	51.6 (39.9)
DC (Jul)	97.3 (50.9)	105.3 (12.2)	101.1 (30.9)	103.5 (25.4)	102.0 (20.2)
DC (Oct)	49.9 (49.1)	78.6 (67.6)	66.9 (61.5)	56.5 (52.7)	53.2 (49.9)

"

in the revised supplement information (Table S9).

References:

Xue, J., Xiao, Z., Bromwich, D.H. et al. Polar WRF V4.1.1 simulation and evaluation for the Antarctic and Southern Ocean. Front. Earth Sci. 16, 1005–1024 (2022). https://doi.org/10.1007/s11707-022-0971-8

- ***Figures 10 and 12 for October: If your temperature field is in error in the stratosphere then so will the specific humidity and wind fields.***

Response:

We appreciate the reviewer's suggestions and will add a discussion on how the simulation errors in specific humidity and wind fields for October in the stratosphere may be related to temperature field errors.

As for humidity, the cold bias in the stratosphere corresponds to the underestimation of atmospheric water vapor capacity, which thus leads to an underestimation of specific humidity in the stratosphere.

Regarding wind speed, the underestimation of temperature corresponds to the expansion of the low-temperature region surrounding the Antarctic vortex, corresponding to a northerly shift in the simulated strong wind belt of the Antarctic vortex, thus the lower wind speeds at McMurdo can be simulated.

Revision in the manuscript:

We have added

"In October, Fig. 10 shows the underestimation of specific humidity in the stratosphere, which may be due to the cold bias (see Fig. 8) in the stratosphere and corresponds to the underestimation of atmospheric water vapor capacity."

in the revised manuscript (lines 426-428, page 23).

We have added

"In October, Fig. 11 shows an underestimation of wind speed in the stratosphere, which corresponds to the underestimation of temperature in the same region (see Fig. 8). This suggests that iAMAS may overestimate the extent of the low-temperature region surrounding the Antarctic vortex, leading to a simulated northerly shift of the strong wind belt associated with the vortex. As a result, lower wind speeds are simulated at MM."

in the revised manuscript (lines 456-459, pages 25-26).

- ***Line 413: Many/most regional models for Antarctica use a polar stereographic projection not a latitude-longitude grid because of the singularity at the Pole.***

Response:

We appreciate the reviewer's comments, and we will revise the statement to clarify that there are few researches on global models using SCVT meshes in the Antarctic, which can avoid polar singularities in Antarctic simulations.

Revision in the manuscript:

We have replaced

"To our knowledge, this is the first instance of an explicit evaluation of a global unstructured mesh over the Antarctic, as previous studies of Antarctic simulations have predominantly utilized regional model with regular latitude-longitude grids."

with

"This study serves as a valuable reference for implementing Antarctic simulations using a global model with an unstructured SCVT mesh."

in the revised manuscript (lines 480-481, page 27).

- ***References: Golledge et al. (2015), Kannemadugu et al. (2023), Kessenich et al. (2023), and Zhang et al. (2023) contain repetitious information.***

Response:

We appreciate the reviewer's careful review and will revise the reference information for Golledge et al. (2015), Kannemadugu et al. (2023), Kessenich et al. (2023), and Zhang et al. (2023).

Revision in the manuscript:

We have replaced

"Golledge, N. R., Kowalewski, D. E., Naish, T. R., Levy, R. H., Fogwill, C. J., and Gasson, E. G.: The multi-millennial Antarctic commitment to future sea-level rise, Nature, 526, 421–5, https://doi.org/10.1038/nature15706, golledge, N R Kowalewski, D E Naish, T R Levy, R H Fogwill, C J Gasson, E G W eng Research Support, Non-U.S. Gov't Research Support, U.S. Gov't, Non-P.H.S. England 2015/10/16 515 Nature. 2015 Oct 15;526(7573):421-5. doi: 10.1038/nature15706., 2015."

with

"Golledge, N. R., Kowalewski, D. E., Naish, T. R., Levy, R. H., Fogwill, C. J., and Gasson, E. G.: The multi-millennial Antarctic commitment to future sea-level rise, Nature, 526, 421–5, https://doi.org/10.1038/nature15706, 2015."

in the revised manuscript (lines 578-579, page 31).

We have replaced

"Kannemadugu, H. B. S., Sudhakaran Syamala, P., Taori, A., Bothale, R. V., and Chauhan, P.: Atmospheric aerosol optical prop-erties and trends over Antarctica using in-situ measurements and MERRA-2 aerosol products, Polar Science, 38, 101011, https://doi.org/https://doi.org/10.1016/j.polar.2023.101011, research Advances from Larsemann Hills, Antarctica: International Coopera-tion and Future Prospects - Part 1, 2023."

with

"Kannemadugu, H. B. S., Sudhakaran Syamala, P., Taori, A., Bothale, R. V., and Chauhan, P.: Atmospheric aerosol optical properties and trends over Antarctica using in-situ measurements and MERRA-2 aerosol products, Polar Science, 38, 101 011, https://doi.org/https://doi.org/10.1016/j.polar.2023.101011, 2023."

in the revised manuscript (lines 632-634, page 33).

We have replaced

"Zhang, S., Xu, S., Fu, H., Wu, L., Liu, Z., Gao, Y., Zhao, C., Wan, W., Wan, L., Lu, H., Li, C., Liu, Y., Lv, X., Xie, J., Yu, Y., Gu, J., Wang, X., Zhang, Y., Ning, C., Fei, Y., Guo, X., Wang, Z., Wang, X., Wang, Z., Qu, B., Li, M., Zhao, H., Jiang, Y., Yang, G., Lu, L., Wang, H., An, H., Zhang, X., Zhang, Y., Ma, W., Yu, F., Xu, J., Lin, X., and Shen, X.: Toward Earth system modeling with resolved clouds and ocean submesoscales on heterogeneous many-core HPCs, Natl Sci Rev, 10, nwad069, https://doi.org/10.1093/nsr/nwad069, zhang, Shaoqing Xu, Shiming Fu, Haohuan Wu, Lixin Liu, Zhao Gao, Yang Zhao, Chun Wan, Wubing Wan, Lingfeng Lu, Haitian Li, Chenling Liu, Yanfei Lv, Xiaojing Xie, Jiayu Yu, Yangyang Gu, Jun Wang, Xuantong Zhang, Yan Ning, Chenhui Fei, Yunlong Guo, Xiuwen Wang, Zhaoying Wang, Xue Wang, Zhenming Qu, Binglin Li, Mingkui Zhao, Haoran Jiang, Yingjing Yang, Guang Lu, Lv Wang, Hong An, Hong Zhang, Xin Zhang, Yu Ma, Wentao Yu, Fujiang Xu, Jing Lin, Xiaopei Shen, Xueshun eng China 2023/05/14 Natl Sci Rev. 2023 Mar 20;10(6):nwad069. doi: 10.1093/nsr/nwad069. eCollection 2023 Jun., 2023."

with

"Zhang, S., Xu, S., Fu, H., Wu, L., Liu, Z., Gao, Y., Zhao, C., Wan, W., Wan, L., Lu, H., Li, C., Liu, Y., Lv, X., Xie, J., Yu, Y., Gu, J., Wang, X., Zhang, Y., Ning, C., Fei, Y., Guo, X., Wang, Z., Wang, X., Wang, Z., Qu, B., Li, M., Zhao, H., Jiang, Y., Yang, G., Lu, L., Wang, H., An, H., Zhang, X., Zhang, Y., Ma, W., Yu, F., Xu, J., Lin, X., and Shen, X.: Toward Earth system modeling with resolved clouds and ocean submesoscales on heterogeneous many-core HPCs, Natl Sci Rev, 10, nwad069, https://doi.org/10.1093/nsr/nwad069, 2023."

in the revised manuscript (lines 735-738, page 36).

RC3: Anonymous Referee #2, 08 Apr 2025

The issue of the low wind speeds at South Pole as reported in this manuscript has been known at ECMWF since January 2019 and is posted on this ECMWF discussion page for ERA5: https://confluence.ecmwf.int/pages/viewpage.action?pageId=129134800 The problem occurs for both the north and south poles. ECMWF Advice: "please use winds at neighbouring locations at 89.75 (N/S) and 89.5 (N/S) for Reanalysis and Ensemble members winds, respectively."

Response:

We appreciate the reviewer's careful review regarding the issue of low wind speeds at the South Pole (90°S). We would like to note that the pole problem for wind speed is supported by ERA5 Climate Data Store (CDS) data. In the revised manuscript, we will clarify the issue of low wind speeds at the South Pole using a more official explanation from the ERA5 CDS. This wind speed issue arises from the method by which winds are derived from vorticity and divergence in spherical harmonic representation when interpolated onto a regular grid in the Climate Data Store. Then, winds at neighboring locations, such as 89.75°S, are used instead of 90°S, because the interpolation at 89.75°S is unaffected and remains normal.

Revision in the manuscript:

We have replaced

"Initially, ERA5 data at SP were extracted from a latitude of 90°S. We found that ERA5 wind speeds are significantly lower than radiosonde measurements (see red circles in Fig. 11). This discrepancy suggests that the ERA5 data may be affected by polar singularity issues, possibly due to the limitations of vector interpolation at the polar grid center (to be discussed later). Subsequently, data from grid points at a latitude of 89.75°S were obtained. We found that the ERA5 wind speeds at 89.75°S are reasonable and do not exhibit the significant underestimation of wind speed, as indicated by the blue crosses in Fig. 11.

Concerning the 3-m wind speed (Sect. 3.1.4), the ERA5 data at SP do not exhibit significant underestimation when compared to AWS measurements. This is because the two AWS sites (HEN: 89.02°S, 1.03°W; NIC: 89.00°S, 89.67°W) at SP are not located exactly at the polar grid center (90°S), thereby avoiding the polar singularity problem. Furthermore, the analysis of ERA5 surface-layer (10-m) wind speeds at a latitude of 90°S also indicates significant underestimation (not shown), consistent with the polar singularity issues identified in upper-air wind of ERA5 data.

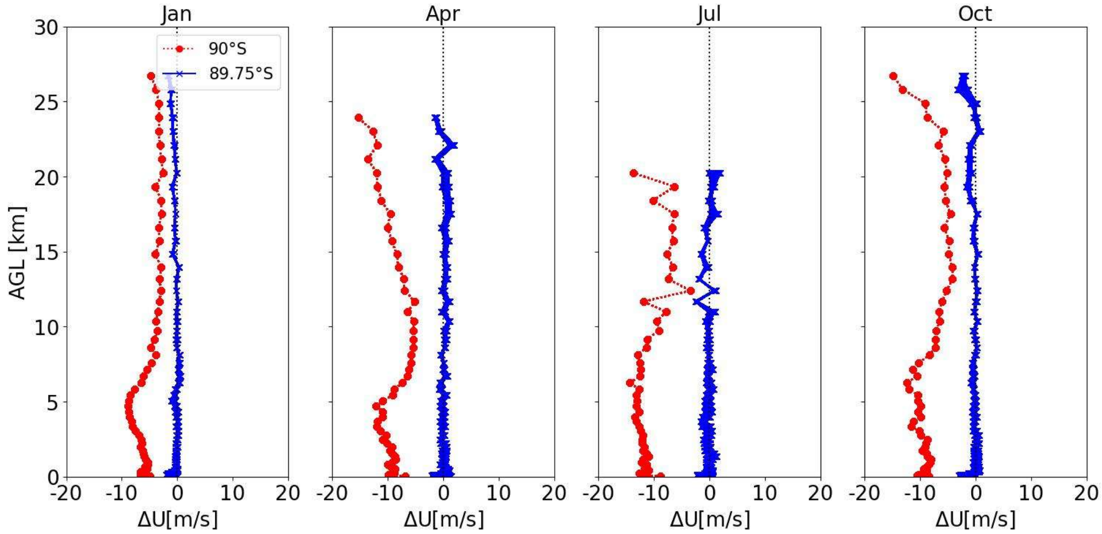

Figure 11. Monthly median values of wind speed biases (ΔU [m/s]) for ERA5 minus radiosondes. Red dots and blue crosses represent the results for 90°S and 89.75°S, respectively. Data are displayed for all longitudes (180°W to 180°E) at both 90°S and 89.75°S. The data for each longitude at 90°S are identical with overlapped points. While the results at 89.75°S exhibit slight differences across longitudes.

Given that the ERA5 wind speed at a latitude of 90°S appears less reliable, then the wind speed at the ERA5 grid point with coordinates 89.75°S, 0°E is utilized. The biases for the wind speed profile are displayed in Fig. 12. The wind speed bias for ERA5 is generally below 1 m s^{-1} in a large part of the atmosphere (see the second column in Fig. 12). The wind speed simulated by all four iAMAS experiments with various resolutions at SP seems unaffected by the ERA5 initialized field at 90°S and yield generally reasonable results. This may be attributed to the limited influence of a single grid point (i.e., the point at 90°S, -°E) on the iAMAS simulations.

Interestingly, we found that the iAMAS simulations can replicate the unrealistically low wind speed values at 90°S after interpolating the iAMAS unstructured mesh to a regular latitude-longitude grid using the Earth System Modeling Framework (ESMF Balaji et al., 2024). Similarly, the ERA5 latitude-longitude grid data are interpolated from a Gaussian grid (Hersbach et al., 2020; Hortal and Simmons, 1991). We argue that the interpolation algorithm for ERA5 wind speeds (specifically, the Uand V-components) is unreliable at the polar grid center at 90°S, as the definition of wind direction becomes inapplicable here. In contrast to wind vectors, scalar quantities do not encounter this directional issue, which explains why temperature, pressure, and specific humidity in ERA5 do not exhibit this polar singularity problems."

with

"ERA5 data for wind speed exhibit polar singularity issues. According to the ERA5 Climate Data Store (CDS:

https://confluence.ecmwf.int/pages/viewpage.action?pageId=129134800), at the poles (i.e., at 90°N and 90°S), the U and V components of the wind are significantly underestimated. This problem arises from the way winds are derived from vorticity and divergence in spherical harmonics representation (the native model format) when interpolated onto a regular latitude-longitude grid in the CDS. Currently, it is not anticipated that this issue will be resolved. As recommended by the ERA5 CDS, data from grid points at a latitude of 89.75°S are used to represent the wind speed at the SP to avoid the polar singularity issues.

Concerning the 3-m wind speed (Sect. 3.1.4), the ERA5 data at the SP do not exhibit significant underestimation when compared to AWS measurements. This is because the two AWS sites (HEN: 89.02°S, 1.03°W; NIC: 89.00°S, 89.67°W) at the South Pole are not located exactly at the polar grid center (90°S), thereby avoiding the polar singularity problem.

The biases for the wind speed profile are displayed in Fig. 11. The wind speed bias for ERA5 is generally below 1 m s^{-1} across a large portion of the atmosphere (see the second column in Fig. 11). The wind speed simulated by all four iAMAS experiments with various resolutions at the SP seems unaffected by the ERA5 initialized field at 90°S and yields overall reasonable results. This may be attributed to the limited influence of a single grid point (i.e., the point at 90°S, -°E) on the iAMAS simulations." in the revised manuscript (lines 442-455, page 25).