Review of
Evaluating the Impact of Enhanced Horizontal Resolution over the Antarctic Domain Using a Variable-Resolution Earth Systems Model
by Tri Datta et al.

General comments :

This paper presents the evaluation of a variable-resolution configuration of the CESM general circulation model (ANTSI) to represent the Antarctic climate over the past decades.
An in-depth assessment of the surface mass balance and energy budget is performed together with a systematic comparison with the standard model configuration (1° regular grid).
The work is serious, the paper is overall well written and the figures are well crafted.
Although I do recognise the merit of this work and even though I overall enjoyed reading this manuscript, I have very major concerns regarding the current version of the paper and unfortunately, I cannot support its publication in the present state. However, I encourage the authors to complement their work. Please find herebelow my major remarks followed by minor comments.

- Although the authors advocate in the conclusion that 'this work suggests that the variable-resolution setup over Antarctica can be a valuable tool for representations of precipitation, surface mass balance ...', using such a simulation configuration for studying polar climates is absolutely not new. Refining locally the grid of a GCM over Antarctica was the approach and methodology of a number of studies, among which pioneering papers by Krinner et al. (Krinner et al. 1997a, Krinner et al. 1997b, Krinner et al. 2007, Krinner et al. 2014). These papers should be cited in the manuscript but besides this, I am therefore wondering what is the real scientific contribution of the present study, beyond the evaluation of a specific configuration of CESM. I'll leave it to the editors to decide if the content of the paper is sufficient to warrant publication

Krinner, G., C. Genthon, Z.-X. Li, and P. Le Van, 1997a: Studies of the Antarctic climate with a stretched-grid general circulation model. J. Geophys. Res., 102, 13 731–13 745, doi:10.1029/96JD03356.

Krinner G, Genthon C (1997b) The Antarctic surface mass balance in a stretched grid general circulation model. Ann Glaciol 25:73–78

Krinner, G., O. Magand, I. Simmonds, C. Genthon, and J.-L. Dufresne, 2007: Simulated Antarctic precipitation and surface mass balance at the end of the 20th and 21st centuries. Climate Dyn., 28, 215–230, doi:10.1007/s00382-006-0177-x.

Krinner, G., Largeron, C., Ménégoz, M., Agosta, C., & Brutel-Vuilmet, C. (2014). Oceanic forcing of Antarctic climate change: A study using a stretched-grid atmospheric general circulation model. Journal of Climate, 27(15), 5786–5800. https://doi.org/10.1175/JCLI-D-13-00367.1

- A variable-resolution GCM is a very powerful tool to study climate at the regional scale and how local features depend on and affect the global climate. However, a climatic study with such a model configuration (without nudging) is fully relevant only if the climate is satisfactorily reproduced at the global scale. This is especially true if one wants to run climate scenario simulations. I thus have the followings questions : How is the global circulation reproduced in ANTSI ? How do global temperatures and radiative fluxes at the top-of-the-atmosphere compare to CESM2-AMIP ? Was a parameters re-tuning necessary for ANTSI ?
Furthermore, as the study focuses on the Antarctic, one may question how the statistics of the climate indices (SAM...) and the main large-scale circulation patterns (wavenumber-3 pattern, ...) which are relevant for the Antarctic climate compare between the two simulations. Part of the answer is already in the supplementary materials.

- Throughout the analysis, it is extremely difficult to disentangle the effect of the enhanced resolution over the Antarctic from that of the change in dynamical core (and therefore change in large scale circulation). This is particularly critical for temperature and melting but also for precipitation which strongly depends on both large scale dynamics and fine scale topographical features. As a consequence, the comparison between ANTSI and CESM2 AMPI is often not fully conclusive or not completely convincing. I would suggest the authors to run an additional simulation using for instance the regular 1° resolution configuration with nudging towards ANTSI down to ~ 60°S (in order to simulate a similar Southern Ocean storm-track and large scale maritime advections towards the ice sheet). See Genthon et al. (2002) for an example.

Genthon, C., Krinner, G., & Cosme, E. (2002). Free and Laterally Nudged Antarctic Climate of an Atmospheric General Circulation Model, *Monthly Weather Review*, *130*(6), 1601-1616.

- Several pieces of literature suggest that ERA5 is the best reanalysis product to represent certain aspects of the Antarctic climate. However, it is definitely not a reference product for a number of variables. First and foremost, ERA5 can absolutely not be used to evaluate the cloud liquid and ice water content in Antarctic clouds (see for instance Silber et al. 2019, Vignon et al. 2021).
Regarding the surface wind, ERA5 strongly underestimates the winter wind speed in the interior and in coastal regions of the Antarctic (Gossart et al. 2019) and I would strongly recommend the authors to use another reference dataset (the AWS network for example).

Gossart, A., Helsen, S., Lenaerts, J. T. M., Broucke, S. V., van Lipzig, N. P. M., & Souverijns, N. (2019). An Evaluation of Surface Climatology in State-of-the-Art Reanalyses over the Antarctic Ice Sheet, *Journal of Climate*, *32*(20), 6899-6915.

Silber, I., Verlinde, J., Wang, S., Bromwich, D. H., Fridlind, A. M., Cadeddu, M., Eloranta, E. W., & Flynn, C. J. (2019). Cloud Influence on ERA5 and AMPS Surface Downwelling Longwave Radiation Biases in West Antarctica, *Journal of Climate*, *32*(22), 7935-7949.

Vignon, É., Alexander, S. P., DeMott, P. J., Sotiropoulou, G., Gerber, F., Hill, T. C. J., et al. (2021). Challenging and improving the simulation of mid-level mixed-phase clouds over the high-latitude Southern Ocean. *Journal of Geophysical Research: Atmospheres*, 126, e2020JD033490. https://doi.org/10.1029/2020JD033490

Minor comments :

l24 : Acronym VR-CESM2 not introduced yet.
L50 : Coupling with ice-sheet models is not very common.
l56 : Note that two-way nesting is possible with certain RCMs.
Section 2.1 : Can you expand a bit more on the physical content of the model (for the relevant parametrisations). In particular, can you give more details on the surface snow scheme ?
Section 2.1.1. 32 vertical levels is a coarse resolution. What is the model top height ? What is the resolution near the surface in the boundary-layer ? In the mid troposphere ? Is it sufficient to capture the katabatic flow correctly ? Same question for boundary-layer clouds ?
L107 : Storage ? Do you mean cpu time ?
L113 : In line with one of my major comment : is the tuning of ANTSI similar to that of CESM2 in the standard configuration ?
L187 : 'discussed in Results' : we are already in the Results section.
L294-297 : Please cite the external literature here.