<u>RESPONSE TO REFEREE #1</u>

In the following, the reviewer's comments are in blue, and our response is in black.

Second round of review of 'Using a multi-layer snow model for transient paleo studies: surface mass balance evolution during the Last Interglacial' by Hoang et al.

I would like to thank the authors for the revised paper, which substantially improves on the original manuscript. I really appreciate the effort made in making it a more scientific paper with a widely extended analysis of the SMB evolution of the Greenland and Antarctic ice sheets over the last interglacial. Also, the methodology and the modelling framework and setup are much clearer now. I only have a few minor comments which should be addressed before the paper is acceptable for publication.

The text would still greatly benefit from a read by a native English speaker.

The authors thank referee #1 for taking the time and appreciating our efforts. Following your comments, we have corrected the grammar errors and improved the word use in the manuscript. In addition, we have also done our best to improve the quality of the manuscript in terms of English writing. We would like to benefit from the publisher's editing services once the manuscript is accepted.

The line numbers in the comments below refer to the revised paper version with tracked changes.

Minor comments

L. 19-20: why would this improvement only be applicable to 'paleo periods'?

We agree with the reviewer. It is not limited to paleo studies. We intended to emphasize the advantages of using iLOVECLIM, which is high computational efficiency, for multi-millennial simulations. We have modified the abstract with this in mind.

L. 108: 'in exponential relationship with' -> 'exponentially after'

Corrected.

L. 110: 'resulted' -> 'results'

Corrected.

Fig. 2: the caption should be extended to explain the different grids and what they represent

We apologize for the missing information. The caption is corrected with the appropriate information as: "Topography of iLOVECLIM for different resolutions: **(a)** NH40, **(b)** NH40 zoomed in Greenland with the red contour indicates present-day ice sheet extent, **(c)** SH40, **(d)** T21 with similar projection as NH40, **(e)** Similar to (d) but zoomed in Greenland and **(f)** T21 with similar projection as SH40."

Equation 1: what are the units of m_runoff?

Thank you for pointing this out. The unit of m_runoff is mWE. d^{-1} and is added to the manuscript.

L. 241: 'during' -> 'for'

Fixed.

L. 242: Specify that sublimation is ignored. Maybe also consider writing out the SMB equation explicitly again.

Done.

Table 1: Specify which years are considered in the present-day case. Specify that Paleo study data are from iLOVECLIM. Why is the mean summer temperature over Antarctica so different in iLOVECLIM for present-day and PI?

We have added more detailed information about the forcings to the table caption and content.

About the mean summer temperature of iLOVECLIM over Antarctica, the presented data is boreal summer (June-July-August) for PI and LIG experiments, while the data for the present-day experiment is from December-January-February. We apologize for the inconsistency. The data has been updated with the correct data (DJF). In addition, the captions of Table 1 and figures with summer temperature (Fig. S4 and S7) have been updated with details on the summer months.

L. 292: 'is' -> 'are'

Fixed.

L- 296-297: To quantify the impact of biases, you need to run simulations both with and without bias correction, no?

This is what we have done, but maybe the sentence is not clear. We have adjusted it as follows: "To quantify the impact of these biases on the SMB simulation, in addition to original climate forcings, we also run BESSI and ITM with the bias-corrected version of iLOVECLIM."

L. 524: in terms of timing yes, but can anything be said about the magnitude?

We have modified the text of Fig.10d as follows: "For Antarctica, the comparison of the simulated local surface temperature of iLOVECLIM and temperature change proxy at EPICA Dome C (EDC) is presented in Fig. 10d. The change in the simulated temperature shows a good agreement with the proxy-based data regarding timing. However, the warming at EDC during the LIG compared to PI in our work is only 0.59ºC, while the value suggested by Jouzel et al. (2007) is about 4.5ºC. This difference might result from the fixed ice sheet mask and topography in our simulations. It is possible that the West Antarctic Ice Sheet was smaller during the LIG, leading to a change in surface elevation and ice extent. This can, in turn, increase the temperature at EDC. This part of warming is not taken into account in our simulations."

L. 699: 'satisfied' -> 'satisfying'

Done

L. 729: check this sentence, sounds weird

L. 729: Possibly add some information on how much of the computation time would be consumed by BESSI in a fully coupled iLOVECLIM with GRISLI setup. Would it really be the bottleneck?

BESSI is not yet coupled to iLOVECLIM-GRISLI so it is not certain to give the prediction of the computation cost once it is done.

This part has been adjusted as follows: "Replacing ITM with BESSI to provide SMB to the ice sheet model GRISLI in iLOVECLIM framework can produce more physical results. Nonetheless, BESSI requires more input variables than ITM, making it more sensitive to certain biases in iLOVECLIM, such as humidity. BESSI is also more computationally expensive (30 years per minute for the T21 grid) than a parameterization like ITM. However, considering the computational cost of iLOVECLIM (500 years per day), the extra cost of having BESSI instead of ITM in the framework is relatively small. In addition, we can be more confident in its response to a change in climate since it explicitly simulates many processes, unlike ITM."

L. 752-753: Do you mean stronger sensitivity to model biases? It seems to me that ITM is responding less to LIG forcings than BESSI.

We have corrected the sentences as: "Notably, the comparison between BESSI and ITM during the Last Interglacial suggests a stronger sensitivity of ITM to the biases in the climate forcings".

L. 875: why is the range different for RH? It seems to contradict the values larger than one in Fig. C2. Also, in the text it is mentioned that humidity is strongly underestimated in iLOVECLIM, but from Fig. C1 and C2 it seems to be overestimated? Is it because in one case you are referring to specific and in the other to relative humidity?

We apologize for the confusion. The text has been adjusted as follows: "In order to avoid extreme value, the ratio $\frac{\overline{X_{ERA5}}}{\overline{X_{iLC}}}$ is limited to be in the range of 0.1 to 10.0. In addition, for relative humidity only, once the bias is corrected, the value is restricted between 0.15 and 1.0 (15-100\%) to avoid unrealistic values."

The color bars of Fig. C1 and C2 have also been adjusted to illustrate better the range of the bias correction factors. These figures indicate an underestimation of relative humidity in the center North of Greenland and the interior of Antarctica. Particularly, the ranges of the ratio of relative humidity between ERA5 and iLOVECLIM are about 1.1-1.5 for Greenland and up to 5.0 for Antarctica. These numbers indicate a substantial underestimation of relative humidity in Antarctica, considering that the normal range is mostly around 15 to 100 %. Similarly, when compared to MAR, iLOVECLIM also underestimates relative humidity, as shown in Fig. S4 and S7.

Generally, a comment on the large SW radiation biases in iLOVECLIM would help to interpret the results. How can SW radiation be almost a factor 10 too low over the ice sheets in the model? I presume this cannot be solely explained by differences in surface albedo, but is somehow related to clouds…? Is the bias larger than a factor 10 (which is the maximum used in the bias correction procedure) during the LIG? Could this (partly) explain the underestimation of melt in the ITM compared to BESSI?

We also noticed the unexpectedly low range of shortwave radiation. The reasons behind this can be the prescribed cloud and fixed vertical radiation scheme inside of iLOVECLIM. Indeed, this problem should be further investigated in future work. A comment about the biases of iLOVECLIM is added to the main text to provide more information.

It is uncertain whether the bias correction factors exceed 10 during the LIG as there are no data for this period. In this work, the bias correction factors are obtained from the present-day climate (1979-2021) and applied to the LIG, assuming the biases are constant with time. However, for the present day, the bias correction factors can be larger than 10, particularly for total precipitation and shortwave radiation. To test the impact of the threshold value, we have run BESSI and ITM with bias-corrected iLOVECLIM during the period of 1979-2021 with no maximum threshold on the bias correction factor of shortwave radiation. The changes in annual mean SMB in BESSI-iLOVECLIM and ITM-iLOVECLIM between with and without threshold for the bias correction factor of shortwave radiation are relatively small, and the SMB patterns remain unchanged, as shown in Fig. R1 and R2. We also do the same test for the time slice 128.5 kaBP when the SMB reaches its minimum value during the LIG. The results of this time slice are similar to the present-day run, as shown in Fig. R3 and R4. For Antarctica, we can see the grid cells with high differences, but the magnitude of SMB change is still relatively small (0.5% for BESSI-iLOVECLIM and 1% for ITM-iLOVECLIM).

Hence, the threshold of the bias correction factors is unlikely to impact the melt simulation in ITM.

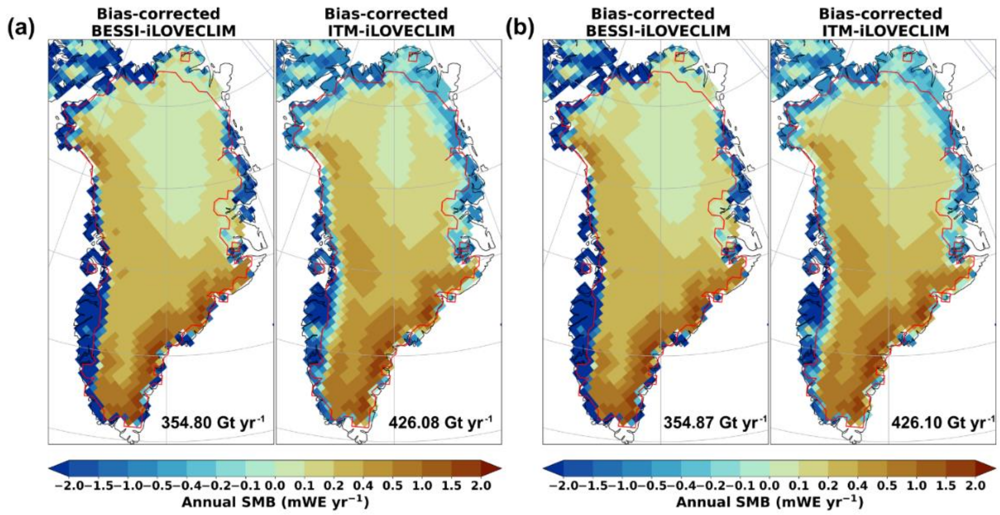

Figure RA1. Comparison of present-day annual mean SMB from bias-corrected BESSI-iLOVECLIM and ITM-iLOVECLIM for experiments with a threshold (10 maximum) **(a)** not applied and **(b)** applied to the bias correction factors of the shortwave radiation.

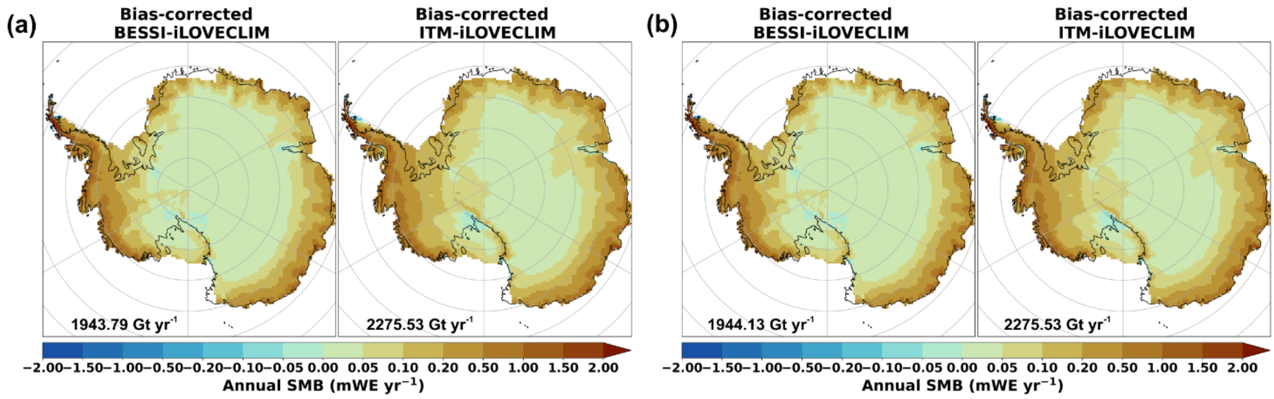

Figure RA2. Similar to Figure RA1 but for Antarctica.

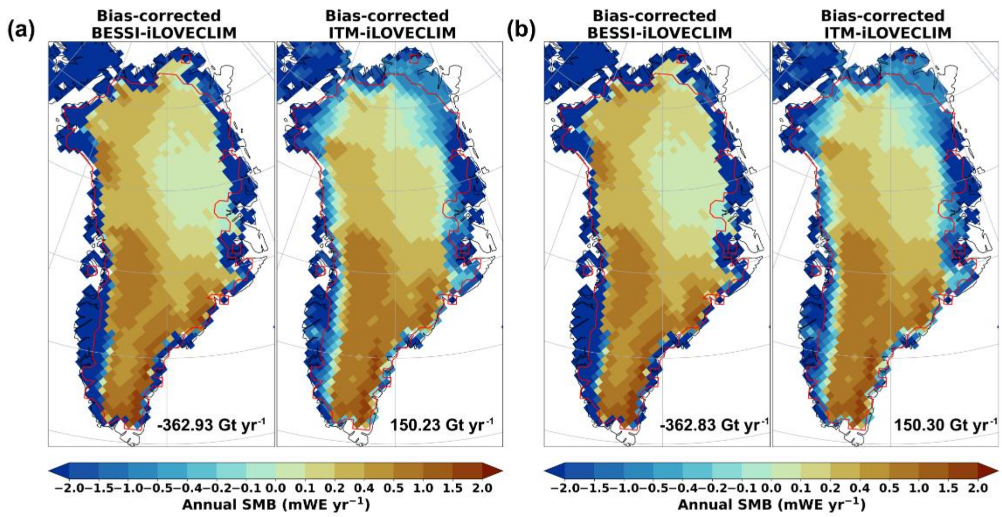

Figure RA3. Similar to Figure RA1 but for 128.5 kaBP.

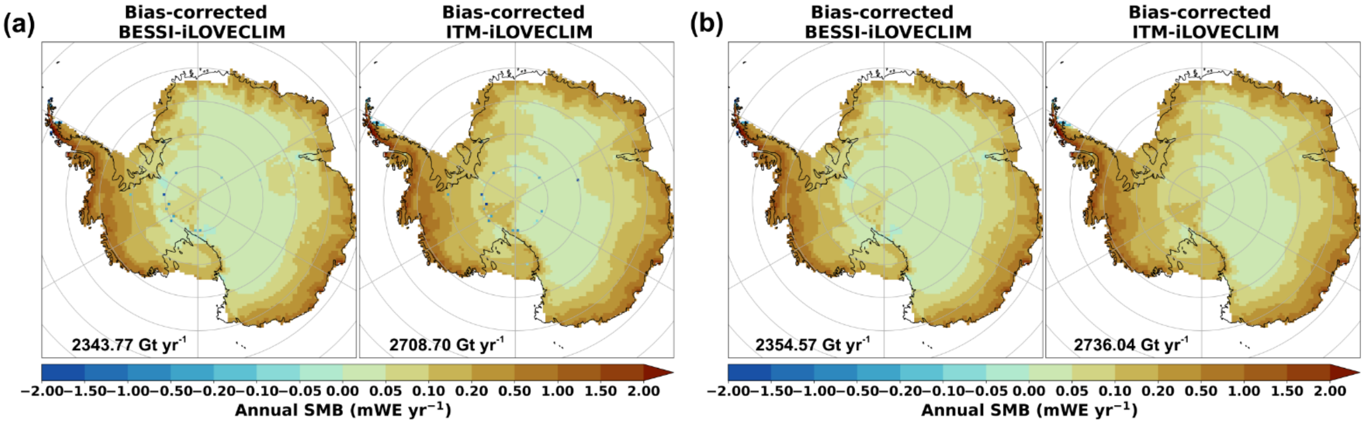

Figure RA4. Similar to Figure RA2 but for 128.5 kaBP.

References

Jouzel, J., Masson-Delmotte, V., Cattani, O., Dreyfus, G., Falourd, S., Hoffmann, G., Minster, B., Nouet, J., Barnola, J.M., Chappellaz, J., Fischer, H., Gallet, J.C., Johnsen, S., Leuenberger, M., Loulergue, L., Luethi, D., Oerter, H., Parrenin, F., Raisbeck, G., Raynaud, D., Schilt, A., Schwander, J., Selmo, E., Souchez, R., Spahni, R., Stauffer, B., Steffensen, J.P., Stenni, B., Stocker, T.F., Tison, J.L., Werner, M., Wolff, E.W., 2007. Orbital and Millennial Antarctic Climate Variability over the Past 800,000 Years. Science 317, 793–796. https://doi.org/10.1126/science.1141038

<u>RESPONSE TO REFEREE #2</u>

In the following, the reviewer's comments are in blue, and our response is in black

Thank you to the author, they have made quite an effort to implement the recommendations by both reviewers. I am mostly satisfied with the revised version, and have only three small concerns:

The authors thank referee #2 for taking the time and appreciating our efforts. We have corrected the manuscript following your comments. The detailed answers are in the following.

Table 1: Please check mean summer shortwave radiation, the iLoveclim values are completely off and I suspect this is not the same variable than for MAR, also is summer insolation in the lower part of the table the same as mean summer shortwave radiation? Maybe use the same variable/name in both cases

We apologize for the confusion.

For the mean summer shortwave radiation, we computed the mean value of the summer months (June-July-August for Greenland and December-January-February for Antarctica) on the corresponding present-day ice sheet extent. The shortwave radiation in iLOVECLIM is lower than in MAR due to the biases of this variable (as shown in Fig. C1 and C2). This issue, together with the biases of relative humidity in Antarctica, will be further investigated in future works.

For the Last Interglacial simulation, the summer insolation refers to the summer insolation at 65°N for Greenland and 65°S for Antarctica.

The table's caption is adjusted to provide more information for the readers as: "Climate characteristics of two different climate forcings: MAR and iLOVECLIM for different experiments. The calibration/validation is carried out from 1979 to 2021 with forcings from MAR and iLOVECLIM. Mean summer shortwave radiation and mean summer temperature are calculated based on the present-day ice sheet extent. The climate forcings for the Last Interglacial (LIG) comes from iLOVECLIM only. The summer insolation of the paleo study corresponds to the summer insolation of 65°N for the Greenland Ice Sheet (GrIS) and 65°S for the Antarctic Ice Sheet (AIS). The summer months are June-July-August for GrIS and December-January-February for AIS."

Fig.8: the bold color is used for the bias corrected forcing of BESSI and for the non-bias corrected of ITM, using bold colors for both bias corrected forcings would be more intuitive.

We have adjusted the color choices as recommended.

Fig. 10 caption should state that isotope values are from ice cores and distinguish whether time series reflect global or local temperatures. Also the text describing Fig. 10 could be more clear in this, maybe also mention effect of height changes for local temperatures.

Thank you for your useful comments.

We have adjusted the caption of Fig. 10 with more description. We now indicate that Fig. 10c-d are local surface temperatures and mention that the proxy data includes the impact of elevation changes while we do not in our simulations. The corresponding text has also been adjusted.