

Response to reviewer comments

I thank both reviewers for their careful copy-edit of the previous draft. I have also carefully re-read the whole manuscript (after not looking at it for a month) and cleaned up a few passages that were hard to follow.

technical staff request

First author responses prefixed with ‘#’

Please number the sections of the supplement according to the guidelines (see "Supplements" at <https://www.geoscientific-model-development.net/submission.html#assets>), i.e. "S1 GSM ensemble parameter sensitivities", "S1.1 Example GSM ensemble parameter sensitivity results for Antarctica", etc.
done

referee #2

All suggestions have been implemented (didn't bother with repeated "#done") unless otherwise indicated.

Minor suggestions (line numbers refer to the manuscript version including track changes):

1.2: “. It is” -> “, which is”

1.4: “last glacial ice sheet”: rephrase

1.7: which “context” are you talking about?

-> "The above context" as explicitly stated

1.47: remove “glaciological”

1.55: “most” was better than “all” if it’s not 100% sure

I know of no other published ice sheet modelling study using more than 6 ensemble parameters

so will stick to "all".

1.59: add a comma after i.e.

1.79: add “sections” before “2.4 and A1”

1.79: spell out PSU3d

1.82: “ice shelf instabilities” -> “ice sheet instabilities”

1.84: add “section” before “2.5”

Table 1 title: “section for description” -> “sections describing these components”

1.138-141: it would be good to discuss this in more generic term, and talk more generally about the grid used and if it is the same between the different components of the model

1.142: “irregularly spaced sigma grid for velocities”: is that just for the velocity or applied to all the fields? You should start by saying how many grids there are and what is common (or not) for all the components of the model. Then you can talk more about the details (in the current form we kind of have to guess as the text goes)

changed to "for the ice dynamics solver"

1.146-149: this is already said in line 138 and following lines

deleted

Eq.5: Why write u_b as a function of τ_b and not the other way

around. Writing the basal stress as a function of velocity here would be more consistent with the rest of the manuscript, like Eq.7. That's also the way it naturally appears in the boundary condition of the model.

this form was chosen for the C_b coefficient, but I've now inverted it as requested

1.345: "consistent 3 pt upwinding": rephrase to explain this more clearly

rephrased to the mathematically precise:

"discretized using a second-order consistent 3 point upwinding scheme."

1.383-385: why does it increase discrepancy?

that is not what is stated, instead "alter" is used and the RMSE discrepancies

are just used as a metric of the impact on activating horizontal heat diffusion in the bed

1.400: remove "crudely" to avoid judgment

1.426: I am confused about the "number of PDDs per day", does it mean the number will be a fraction of a day?

I've added a definition of PDDs to clarify:

"PDDs for any day are herein defined as the hourly resolved time average of the maximum of 0 and the near surface air temperature (in degrees Celsius)."

1.453: "uses a" -> "uses an"

1.488: missing comma after "i.e."

1.554: "a ensemble" -> "an ensemble"

1.648: Why a depth a 200 m chosen for the threshold?

to route runoff into the continental shelf for coarser grid climate model coupling.

Too fine a detail to worth mentioning here

Fig.5 title: "example GSM" -> "example of GSM"

1.689: "high variance" -> "higher variance"

1.720: missing word after "Year and monthly"

added "dependence"

1.747: spell out "CCM"

1.810: "is obtain" -> "is obtained"

1.835: "subject to the factor": how is that applied?

as a multiplicative factor, inserted "multiplicative" to make this clearer

Figure 7 caption: "Example process" -> "Example of process"

1.987: I am surprised the default is "210 kyr" compared to the 500 or 1000 years mentioned above

210kyr is the total length of the interval at 500 or 1kyr time resolution, now clarified

by revised placement of "(default 210 kyr)"

Figure 8 caption: spell out RSL

1.1002: "Han et al. (2022)" -> "(Han et al. 2022)"

1.1027: missing parenthesis after "Pa s"

1.1055: for the sea level, does it include the other terms outside of the ice sheets like the ocean thermal expansion?

No, and ocean density changes are usually not accounted for in GIA

models, especially for paleo contexts

A key challenge would be the need for a reasonably well constrained

3D temperature field of the ocean through a glacial cycle.

1.1080: "approximations of" -> "approximations for"

I disagree given the context and given a comparative search on the internet

Table 7 title: It is unclear if it's key or most or what? Also "with year": does that mean every year or annually?

removed confusing "(mostly) primary"

1.1136: "as inferred BedMachine" -> "as inferred from BedMachine" (or based on BedMachine)

1.1145: add comma after contexts

1.1150: extra comma to remove

1.1192: add ":" after "following"

Nope, since the subsequent list is composed of separate sentences

ref #1

155 "Verjans et al., 2022)."

Add opening parenthesis

opening was farther up the sentence. Added 'c.f. ' to make phrase sequencing clearer

1117 "Tables 2"

-> "Table 2"

Table2.

Maybe "North American and Eurasian specific" in line with Table 3.

done

1138 "2.3 A caveat on parametrizations in the GSM"

It seems 2.3 should follow right after 2.1.

switched 2.1 with 2.2

1274 "The GSM has not been setup"

--> "The GSM has not been set up"

1352 "A near unique feature is"

--> "A near unique feature of the GSM is"

1414 Figure 3.

The figure would be easier to read if the x and y axes had the same range. Even better if the axes aspect ratio would be 1, which anyhow works better in a 2 column paper.

done

1463 Figure 4.

Consider aspect ratio of 1 for the axes.

done

1498 "A related limitation is the plume model is purely buoyancy driven"

-> "A related limitation is *that* the plume model is purely buoyancy driven"

1521 "B= 0.15 oC-β mday-1 as per Rignot et al. (2016) assuming an average of 180 melt days"

For the justification of B I find "B expresses that q_m is nonzero in the absence of subglacial water flux" in Rignot et al. (2016). Where does the assumption of 180 melt days come from? Wouldn't the amount of melt days change in e.g. a glacial or much warmer climate?

This was burying a bunch of uncertainties, which I now address explicitly,
by deleting the above "assuming an average of 180 melt days" and inserting:
"An extra factor of 0.5 is also inserted in this rescaling to partially account for the impact of using annual mean inputs, given that intra-annual variations are largely driven by changes in q (annual averaging will increase the effective value of q^a given that $a = 0.39 < 1$). The application of eq. 25 in the GSM introduces uncertainties arising from the coarser grid scale resolution typical of paleo ice sheet modelling as well as limitations in the required inputs and their averaging to annual means. As such, an ensemble scaling parameter (C_{face}) is added. "

1527 "the GSM has the option of switching the ensemble parameter to the A coefficient"
Not clear what that means.

changed ->
"the GSM has the option of making the A coefficient the ensemble parameter (...)."

1608 "The mass-conserving solver"
--> "The mass-conserving surface drainage solver"

1643 "August–February differences range up to 0.30 over the last two glacial cycles for the EBM derived monthly glacial index"
What is the reference for this result? Or refer to the EBM section below?
the EBM derived index is described in the next paragraph, so just appended:
"described below"

1646 "with the much high variance of winter temperatures"
--> "with the much *higher* variance of winter temperatures"

1675 "Year (ty) and monthly (tm) "
Maybe "Year (ty) and month (tm)"?
-> Yearly (ty) and monthly (tm)

1711 "have also shown that strong grid resolution dependence"
--> "have also shown a strong grid resolution dependence"

1718 "under predict"
--> "underpredict"

1736 "CPEOF(i) and CTEOF(i)"
Add opening parenthesis

1740 "with the former have no Keewatin ice dome"
--> "with the former having no Keewatin ice dome"

1755 "A third temperature forcing component option for Antarctica"
Maybe "developed for Antarctica" or "specific for Antarctica"

1762 "is obtain with"
--> "is obtained with"

1778 "(Θ P) parameterize"
--> "(Θ P) parameterizes"

1817 "wind velocities ((UGCM))"
add extra closing bracket
removed extra opening bracket

1832 "CESM Earth system model"
The model was called "National Center for Atmospheric Research
Community Climate System Model version 3" or "NCAR CCSM3"

1840 " $r_{\text{ToceanBiasCor}} + r_w (1 - r_{\text{ToceanBiasCor}})$ "
Better formatted as an equation.
I've just created a separate equation for $\text{Tocean}(t,x,y)$ to make all this clearer

1849 "this inadequacy was assigned to this uncertainty, especially since this required"
A lot of "this" in this sentence.
rewritten to
"As the largest component of relevant climate
forcing uncertainty is the subshelf ocean temperature, we ascribe this inadequacy
to ocean temperature uncertainties. The latter are especially large
given the required spatial extrapolation of the TRACE ocean fields which do
not cover the Antarctic ice shelf sectors."

1866 "(Hughes et al., 2016; Dalton et al., 2020, 2022)"
Move to end of sentence or after "margin chronologies".

1925 "The load history must be stored as spherical harmonic
coefficients and thereby represents a major memory load" Similar to
1915 "This convolution necessitates storage of the discretized load
change history."
Combine?
done

1934 " $(2 \times 10^{20}$ and 3×10^{21} Pa s respective upper and lower mantle viscosities"
Add closing parenthesis

1942 "load history time-steps Han et al. (2022)"
--> "load history time-steps (Han et al., 2022)"

1960 "in that improvements"

Something missing?
just deleted the above

1962 "(upper mantle viscosities were $<1 \times 10^{21}$ Pa s, lower ranged from 1×10^{21} to 30×10^{21} Pa s"

Not sure where to close the parenthesis. Something missing?
closing now added to end of above quote

11000 "sign preserving square"
--> sign-preserving

11039 "(Pollard et al., 2015). It has already been"
--> "(Pollard et al., 2015), it has already been"

11071 - 11074

This paragraph feels out of place here and may be better placed at the end of 2.3.
actually better fit for the "GSM parameters" subsection (now 2.2), so moved there

11111 "GIA model step at the cost of repeat iteration of the the ice sheet dynamics"
--> "GIA model steps at the cost of repeat iteration of the ice sheet dynamics."

11132 "isochronal depth inversions (MacGregor et al., 2015)"
A more recent update exists: <https://doi.org/10.5194/essd-17-2911-2025>
updated

11135 "Depending on community interest and involvement"
Since the authors in their reply express hope to establish a community around the model, I recommend proactively publishing and maintaining the code in a more accessible place like GitHub.

My (LT) old school workflow right now doesn't use Git. A move
towards that approach would need some time investment on my part and
given my perpetual overload, I'm only willing to do that if there is
some concrete interest expressed. I have added a statement to my
website so that potential users who would like a gitHub setup can
send me a brief note. If there is some concrete interest from more
than two respondents I will work through the GitHub conversion.

11171 "Nested flow charts are as follows. Relevant GSM subroutine or variable names are shown within parentheses and relevant source files are enclosed with square brackets."
Description should be moved to the Figure caption.
done

11176 "delt is halved"
delt and other parameters appearing in the text should probably be formatted differently. This is particularly easy to confuse with normal text.
-> italics