

# Response to the comments of the editor for the manuscript "Stabilizing feedbacks allow for multiple states of the Greenland Ice Sheet in a fully coupled Earth System - Ice Sheet Model"

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We would like to thank Alexander Robinson for his valuable comments and specifically for his suggestion to rename the experiments. We have carefully revised our manuscript according to the comments of the editor along with some minor linguistic changes.

We provide a detailed point-by-point reply to all comments below. The editor's comments are presented in regular font, the authors' replies in [turquoise font](#), and changes to the text in *italic green* font.

All authors have read and approved the suggested changes. We appreciate the opportunity to enhance our manuscript and are delighted that our manuscript is considered for publication.

Kind regards,

Malena Andernach, Marie-Luise Kapsch and Uwe Mikolajewicz

## Response to the editor

You have thoroughly addressed all of the comments of the reviewers. The manuscript is nearly ready for publication. It is clearly interesting work and worthy of publication, but I believe the manuscript itself could be improved for clarity. Please find one major general comment and several additional minor comments below that should be addressed in a revised submission.

I have one general comment that I think is important. I find the naming convention for the experiments very confusing. I understand that the state names L\_G, M\_G, S\_G and XS\_G refer to the final states, ie what comes out of the experiments, and this seems fine and useful. But I think it does not make sense to include these in the names of the experiments that you run. Rather the experiments should tell the reader something about what was imposed. The distinguishing feature first of all is the initial state as defined by its volume. So I would propose that you simply name the experiments by the volume they started with, like [v00, v21, v43, ...] corresponding to initial volumes [0%, 21%, 43%, ...]. You could also simplify the suffixes, from "cL\_A" to "A\_PD" (for Antarctica present day) and "L\_oce" to "O\_PD" (for Ocean present day) or "O\_LG" (for Ocean large Greenland).

With this formulation, you can also avoid defining a "meta-stable" state - and rather discuss the fact that some simulations that appear to stabilize to an M\_G volume, eventually transition to an S\_G state, which has been shown before (Zeitze et al., 2022; Bochow et al., 2023).

We thank Alexander Robinson for reviewing our manuscript and for his overall positive feedback. As suggested, we changed the naming convention of the experiments. Each experiment is now named after its initial GrIS volume. For example, the simulation initialized with a GrIS volume of 33% is named g33, where "g" stands for GrIS. We also adjusted the suffixes of the AIS and ocean sensitivity experiments to "pi\_a" and "pi\_oce", respectively. Lastly, we removed the formulation of a metastable state and discuss that similar behavior has been shown before.

General: Make sure that multiple references at a time appear in chronological order.

We verified and changed the order of the references.

L1: Remove "To this date,"

We modified this.

L3: complex → comprehensive

We changed this.

L16: "particularly sensitive" ← The cited references indicate that there is currently strong global warming over Greenland, not that the GrIS is sensitive to it. Please rephrase or modify the references accordingly.

Thanks for pointing this out. We revised the sentence.

L22: gets → becomes

We modified this.

L33: several stable states → more than one stable state

We revised this accordingly.

L89: investigations → investigation

We corrected this.

L93: their contribution to → and its impact on

We modified this.

L97: GrIS' → GrIS's

Thanks for spotting this.

L98: a conclusion → the conclusions

We changed this.

L115: Further, the → The model also

We revised this.

L127: 100 years-long → 100-year-long

We added the hyphen.

L145: branched of → branched off

Thanks for catching this.

L146: Out of curiosity, what was the reason behind the arbitrary volumes (21% or 43%) to branch off

from?

Initially, we designed only 5 experiments to investigate the potential multiple steady states of the GrIS. The first two experiments were set up with 100% and with 0% of PI GrIS volume. We continued the run initialized with an ice-free Greenland under slowly decreasing CO<sub>2</sub> concentrations and branched off simulations each time the GrIS had reached a significantly new geometry (at 21%, 43% and 70% of its PI volume). After having found multistability of the GrIS in our model, we added the remaining experiments to investigate the multistability and potential thresholds systematically.

L146: Also out of curiosity, why did you explore regrowth of the GrIS from states that were growing from ice-free conditions? Since the manuscript is often focused as exploring reversibility of partially melting the ice sheet, I would have expected the initial states to come from deglaciation experiments rather than reglaciations. Could you add an explanation for this choice?

The study of the multistability with simulations branched off from a regrowing GrIS is due to our initial idea of studying whether the GrIS could regrow from ice-free conditions. As we were analyzing the results, we decided to change the perspective to one from a retreating GrIS, as this more closely aligns with the recently accelerated melt of the GrIS. Due to the significant computational demands associated with running fully-coupled ESM-ISM simulations over tens of thousands of model years, we opted to focus on these simulations rather than repeating them for a retreating GrIS. Whether the experiments are branched off from a retreating or regrowing GrIS should not affect the final steady states, as the steady states are maintained through their individual geometry (including elevation, surface albedo, land cover and the dynamic consequences). We would prefer to not add this explanation to the text.

L147: "From the five simulations, we obtain three final GrIS states" ← I would suggest refraining from mentioning this now, or defining the final state names, as these are your results. In this section, it would be more clear to stick to the experimental setup alone. See also the next comment.

We agree and removed all mentions of the final states.

L151-156: Why is this treated as a different set of experiments? Unless there is something fundamentally different about these, which doesn't seem to be the case, it would be much clearer to say from the beginning that you branched off at (17%, 21%, 33%, 43%, 50%, 67%, 70% and 83%), and obtained four additional steady states: L\_G, M\_G, S\_G and XS\_G. This would also then be clearer on L132 that you ran 10 experiments starting from different initial states. It could be that you ran these experiments subsequently in practice, but I see no reason not to present them as one set of simulations.

Thanks for your suggestion. We revised the description of the experimental setup accordingly.

L166: interpolated → mapped

We changed this.

L185: XS\_G) → XS\_G, respectively)

We added this.

Figure 2: I think this figure could be both simplified and improved. Here are a few suggestions:

- Again I don't understand the difference with the so-called "threshold experiments" given by light lines. I think these could also just be shown as the same thickness here and not distinguished from the other simulations.
- Keep the left y-axis in units of percent PD volume, since this is what is referred to and used to define the experiments mostly. On the right-y-axis, you could put the actual GrIS ice volume for reference. Then you would be able to remove the % labels near year 0, since they would

appear on the y-axis directly. You could include the simulation label there, as I proposed above, something like v17 etc, which would correspond well with the axis.

- As I mentioned, I do not think it is valuable to add a label like M<sub>G</sub>\*. I think the color of the line would be more intuitive if it is just prescribed based on the final volume of the simulation. You could identify these groups with one label of the percent that is most representative.
- To me the percentages associated with each identified stable state that would be better as 20%, 30%, 50% and 100% - there is no need to keep 2 digits of precision here. This would simplify the figure, and your message itself.

Thank you for your suggestions on our figure. We updated it in the following way:

- We removed the formulation of "threshold experiments" (see also our previous replies) and adjusted the design of the formerly "threshold experiments" to the regular experiments.
- We added a second y-axis. The left axis shows the percentage and the right axis the volume.
- We replaced the initial ice volumes by the names of the experiments (e.g., g33).
- We replaced the individual final GrIS volumes by one value and label for all similar experiments.
- We changed the coloring and name of g43 (formerly M<sub>G</sub>\*).
- We rounded the final volumes to 20%, 30% and 50%.

L222: effect → increase

We changed this.

Figure 3: Is it possible to have more labeled tick marks for the colorbar of the 2m temperature difference? As it is now, it is hard to gauge the magnitude of the red anomalies, which represent the important feature we would like to see.

Thanks for your suggestion to improve the figure. We added more labeled ticks.

Figure 3, caption: the remaining columns the → while the remaining columns show the

Thanks for spotting this. We revised it.

L241: Further, the smaller GrIS in XSG is preserved → The smaller GrIS in X<sub>-</sub>SG is also reinforced

Thanks. We revised this.

L259: In absence → In the absence

We changed this.

L267: originates of → originates from

We revised this.

L288: "To indicate its weak stability, we assign an asterisk to its name." ← In line with above general comment on naming conventions, I believe you could just delete this statement. Explicitly defining a kind of M<sub>G</sub>\* state is not necessary, and at least would require more analysis. It is likely not the fact of starting at 43

Thanks for the suggestion. In line with our previous replies we removed the asterisk.

L303: ice thickness → reduction in ice thickness

Thank you for your suggestion. However, we would like to keep this formulation, as it is supposed to be a general description of the effect, which can be stabilizing or destabilizing depending on whether you compare it with the smaller or larger neighboring state.

L303: the counteractive GIA → the uplift via GIA

Also here, it is supposed to be a more general description of the effect, where the bedrock can be uplifted or suppressed compared to the neighboring state. We slightly modified the formulation to: "*... counteractive isostatic adjustment of the underlying bedrock ...*".

L305: the overall elevation feedback remains positive (destabilizing) → the net impact of these two feedbacks is destabilizing [They are two different feedbacks, one is positive and one is negative. Their impacts can be combined, but not the feedbacks themselves.]

Thanks for spotting this. We revised it accordingly.

L308: Delete "with a small than"

We revised the sentence. The modified sentence reads as "*... the higher surface elevation and larger glacier mask than in  $X_{S_G}$  stabilize the  $GrIS$  in  $S_G$ .*"

L309: precipitation feedback opposes → precipitation changes oppose

We revised it to "*feedback with the precipitation*".

L310: ice sheet expansion → ice-sheet expansion

We added the hyphen.

L313: ocean feedback → ocean

We removed "feedback".

L315: ocean-effect impact ← rephrase

We rephrased it.

L316: ocean feedback → ocean changes

We changed this.

L317: ocean feedback → ocean

We would like to keep "ocean feedback", as it is not the ocean in general that prevents the retreat but the changed ocean properties in response to the changed  $GrIS$ .

L325: positive → stabilizing

We changed this.

Table 2: This table has some value, but visually this table is somewhat hard to handle, and the transition from bold to normal changes the size of the symbols. I would propose using colored rectangles (ie a heatmap with a colorbar) for this table instead of the symbols and font style. You could also consider using numbered categories for your intervals -4, -3, -2, -1, 0, 1, 2, 3, 4.

Thank you for the suggestion. We replaced the table by a heatmap, which shows the different contributions in color and in numbered categories.

Figure 7a: Make analogous changes as to Fig. 2.

We updated the figure according to your suggestions.

Figure 7, caption: Please rephrase for precision, particularly for "(a) ...", ie, "Time series of ice volume evolution of the AIS...."

We modified the figure caption.

L369-370: "imposing a large AIS in the simulation with a prescribed large AIS" ← redundant, please revise.

We revised the sentence accordingly.

L387: 4 Summary & discussion → 4 Discussion [Some level of summary is implied, and a Conclusions section comes later in any case.]

We changed the title.

L390: model → modeling

We changed this.

L406-408: "If such a sea-level rise occurred in reality, it would threaten many coastal ecosystems and communities (Hallegatte et al., 2013; Nicholls and Cazenave, 2010)." ← This sentence could be removed. It is not really relevant to the current study, as there is no timescale involved, and it would certainly not be a short one.

We removed the sentence.

L409: remains to be investigated with → should be investigated further with other

We modified this.

L424: feedback → interactions

We replaced "feedback".

L434: sea surface effects → sea-surface effects

We added the hyphen.

L480: highly complex → comprehensive

We changed this.

L480: comprehensively → systematically

We replaced this.

L487: an inclusion of dynamic ice sheets → the inclusion of ice-sheet dynamics

We modified this.

L488: essential to study → valuable for studying [I don't think "essential" is warranted.]

We changed this.

Code availability: Edmond → the MPI data repository Edmond

We added this.

Figure B1, caption: but including the feedback of → but including the impact of imposing

We changed that.