Response to the comments of reviewer 1 for the manuscript "Stabilizing feedbacks allow for multiple states of the Greenland Ice Sheet in a fully coupled Earth System Model"

by M. Andernach, M.-L. Kapsch and U. Mikolajewicz

December 2025

We would like to thank Peter Langen for his valuable comments and specifically for his suggestion to highlight the feedbacks that maintain the steady states. We carefully considered the feedback provided and revised our manuscript accordingly.

We provide a detailed point-by-point reply to all comments below. The reviewers' 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 looking forward to your feedback.

Kind regards,

Malena Andernach, Marie-Luise Kapsch and Uwe Mikolajewicz

Response to reviewer 1

This manuscript investigates the potential multi-stability of the Greenland Ice Sheet (GrIS) using a fully coupled climate–ice sheet model under pre-industrial climate conditions. The existence of multiple steady states of the GrIS is not new, but this study provides a fresh and valuable contribution by employing a fully coupled model configuration and identifying four distinct equilibrium states at approximately 100%, 48%, 28%, and 19% of the pre-industrial ice volume.

The paper is well written, clearly structured, and scientifically solid. It is thoroughly embedded in the existing literature and successfully highlights both the consistency with, and the departures from, earlier work. The study thus adds important nuance to our understanding of Greenland Ice Sheet stability and the role of climate–ice sheet feedbacks.

I recommend acceptance with minor revisions. The manuscript is already strong, and the suggestions below are primarily aimed at clarification, readability, and strengthening the framing around stabilizing feedbacks.

We are grateful for the overall positive feedback of our analysis of the impact of a disintegrated Greenland Ice Sheet (GrIS) on the atmosphere and ocean. We thank the reviewer for taking the time to review our manuscript.

Focus on stabilizing feedbacks and suggested summary table: The title emphasizes stabilizing feedbacks as key mechanisms allowing for multiple steady states. Given this framing, the paper would benefit from a clearer and more systematic presentation of which feedbacks dominate and how they differ among the identified equilibria.

I suggest including a summary table (e.g. in Section 4) listing the four steady states and the corresponding stabilizing feedbacks that maintain each. If the same mechanisms apply across all states, this could be explicitly stated. Such a synthesis would align the manuscript with its title and improve clarity for readers.

	ice thickness	GIA	glacier mask	precipitation	ocean
$XS_G \to S_G$	**++++**	- -	**++**	-	+
$S_G \to M_G$	**++++**	- -	**++**	-	+
$M_G \to L_G$	**++++**	-	**+++**	+	-
$S_G \to XS_G$	- - - -	**++**	- -	+	-
$M_G \to S_G$	- - - -	**++**	- -	+	-
$L_G \to M_G$	- - -	**+**	- -	+	+

Table 1: Contribution of the different feedbacks and processes between the GrIS and the climate system to stabilizing the steady states. The number of signs indicates the magnitude of the contribution of the respective factor to stabilizing (minus signs) or destabilizing (plus signs) a GrIS state. It is calculated as the spatially-averaged difference between the SMB field of each steady state and the SMB field of this state including the indicated feedback based on its neighboring GrIS state in Appendix B (e.g., SMB of XS_G minus the SMB calculated under the climate of XS_G but with the precipitation scaled to the precipitation field of S_G). The spatial averages are computed for the non-overlapping area between the two different glacier masks in central Greenland (solid and dashed lines in Appendix B), excluding scattered coastal grid cells. The upper half of the table shows the contributions for a transition from a smaller into a larger GrIS state and the bottom half of the table for a transition from a larger into a smaller GrIS state. The intervals used for scaling are: 0-50 mm WE yr^{-1} (regular-font minus), 50-249 mm WE yr^{-1} (bold-font minus sign), 250-749 mm WE yr^{-1} (two bold-font minus signs), 750-1499 mm WE yr^{-1} (three bold-font minus signs) and ¿1500 mm WE yr^{-1} (four bold-font minus signs) for negative feedbacks and mirrored for positive feedbacks indicated by plus signs. Note that *glacier mask* also includes the albedo feedback.
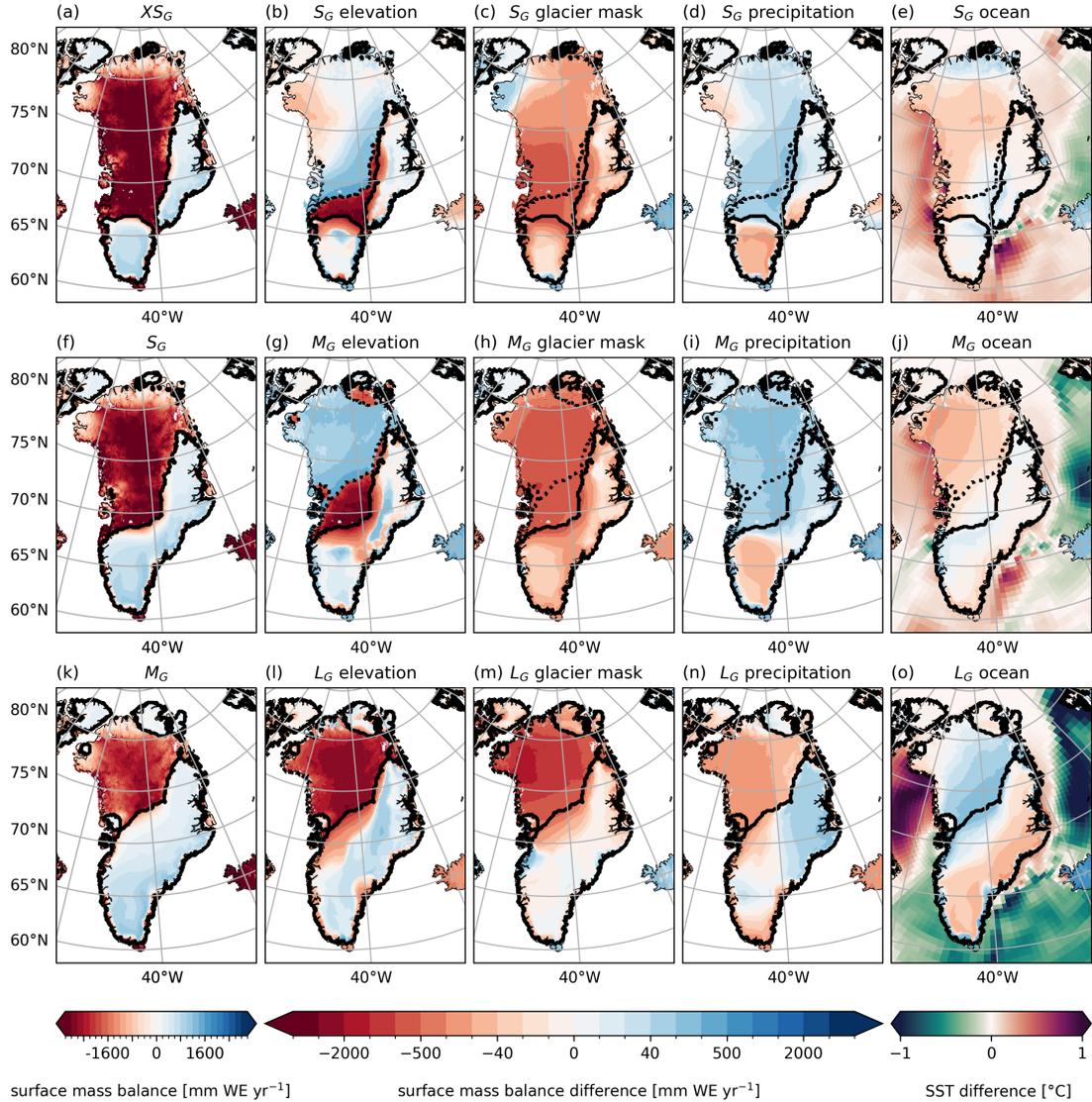
Figure 1: Maps of SMB indicating the contribution of the different feedbacks and processes between the GrIS and the climate system to stabilize each state. The left column shows the absolute SMB field of each steady state. The remaining columns show the difference between the SMB field derived for each state and the SMB field derived for the state but including the feedback of the neighboring state that is indicated in the figures' title. A positive SMB indicates that the respective factor favors maintaining the state or even an ice sheet expansion, thus is stabilizing. A negative SMB indicates that the respective factor impedes an ice sheet expansion or even favors retreat, thus is destabilizing. The solid black line indicates the glacier mask of the respective steady state and the dashed black line of the next larger steady state. The spatial averages presented in Table 1 are computed for the non-overlapping area between the two different glacier masks in central Greenland, excluding scattered coastal grid cells. Note that *glacier mask* also includes the albedo feedback. The far-right column also displays the SST difference of the smaller minus the larger state.
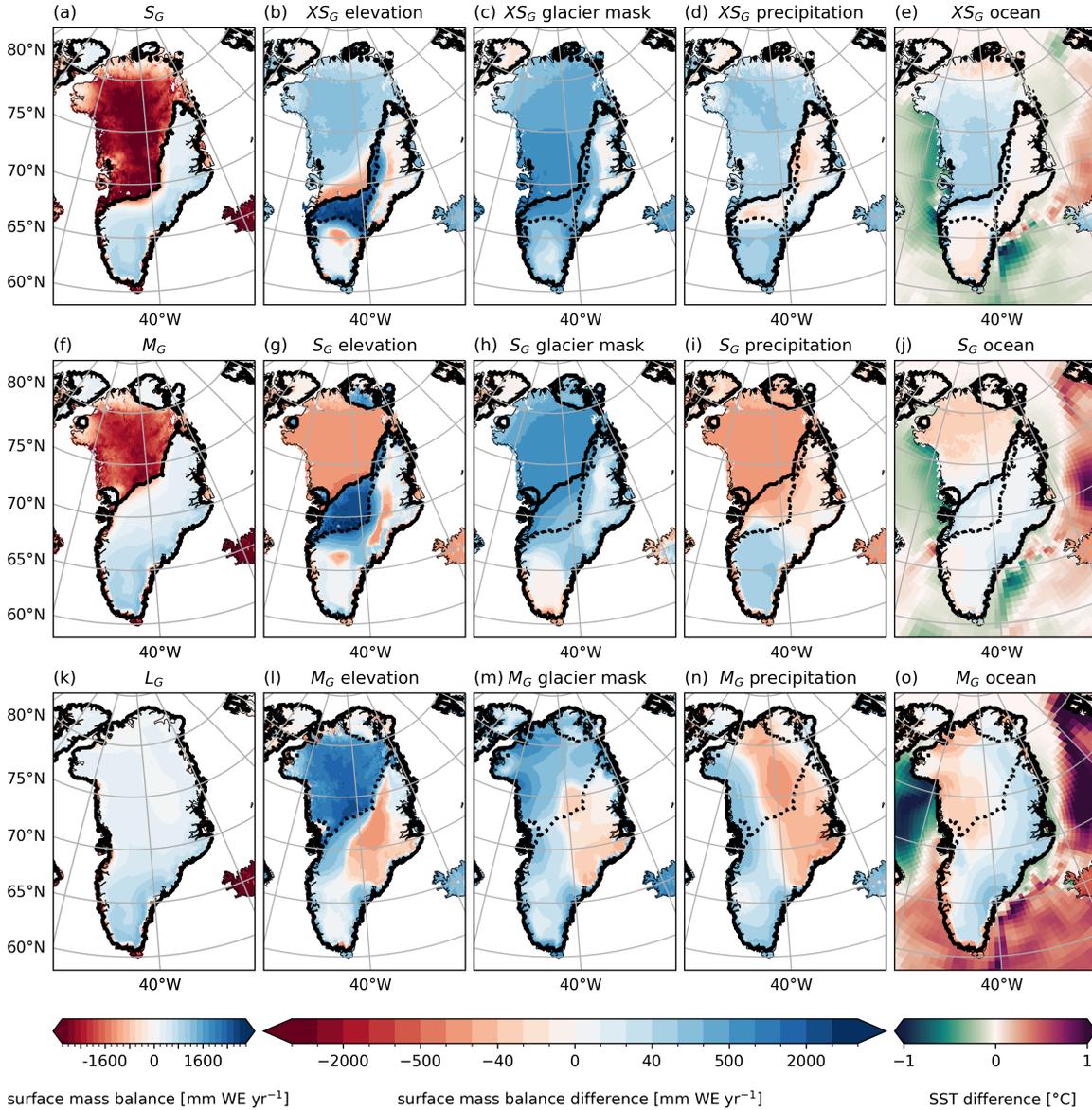
Figure 2: Similar to Figure 1 but for the neighboring smaller state.

L7–8: "These steady states are stabilized through several feedback processes, such as the melt-elevation and melt-albedo feedback."
Please clarify whether the melt–elevation and melt–albedo feedbacks are indeed stabilizing. These processes are usually considered positive feedbacks (destabilizing). Are they stabilizing only in certain states, depending on basin of attraction? A brief explanation of when and how their sign changes would be useful.

Thanks for pointing this out. The way we phrased it could be misleading as they are typically destabilizing feedbacks. Therefore, we slightly modified the sentence: " *These steady states are stable through the interplay of several feedback processes. The most important are the melt-elevation and melt-albedo feedback.*"

L12: "highlight the importance of climate–ice sheet feedbacks"
Consider adding "fully coupled", as this aspect is a major strength of the study.

Thanks. We changed this accordingly: *"highlight the importance of fully coupled climate–ice sheet*

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feedbacks"

L61–69: You mention stabilizing feedbacks via isostatic adjustment and freshwater release into the North Atlantic. Could you clarify whether these are active in your simulations and, if so, whether they appear among the feedbacks constraining your steady states? If they are not significant here, a short note acknowledging that would be helpful.

Yes, isostatic adjustment and freshwater release from the melting ice sheets is included in the model and they also contribute to the emergence of the four steady states. We find that the bedrock elevation of Greenland rises locally by several hundred meters after the partial to complete disappearance of the GrIS. This effect slightly counteracts the melt-elevation effect, by raising the surface bedrock by several hundred meters. However, the raise it not strong enough to allow for a regrowth after disintegration. We added the contribution of the GIA feedback to the mentioned table, added a figure of the isostatic adjustment (Fig. 3) and also an explanation to the text: "In the center and the north of Greenland, a strong lapse-rate effect due to the lower surface elevation of up to $2300\,\mathrm{m}$ (XS_G compared to L_G) inhibits ice sheet formation by raising temperatures. This lapse-rate effect also explains why the highest temperature anomaly occurs in central and northern Greenland (Fig. 3). *Although the warming effect of the lower surface elevation due to the lower ice thickness GrIS is slightly counteracted by GIA effects, which raises the bedrock surface by up to 600 m over central Greenland (Fig. 3), cooling through GIA is not sufficient to allow for an expansion of XS_G.*" Freshwater release from the melting GrIS could impact the SST and salinity of the North Atlantic, the stability of the water mass and therefore the AMOC. The impact of SST and AMOC on the steady states is analyzed in the present manuscript in l.220-231 and discussed in l.359-362 and l.377-380. We further pointed out the importance of the AMOC and SST changes on the state transition of M* (l.246-251) and in the sensitivity experiments with a constant PI AIS (Section 3.3.2).
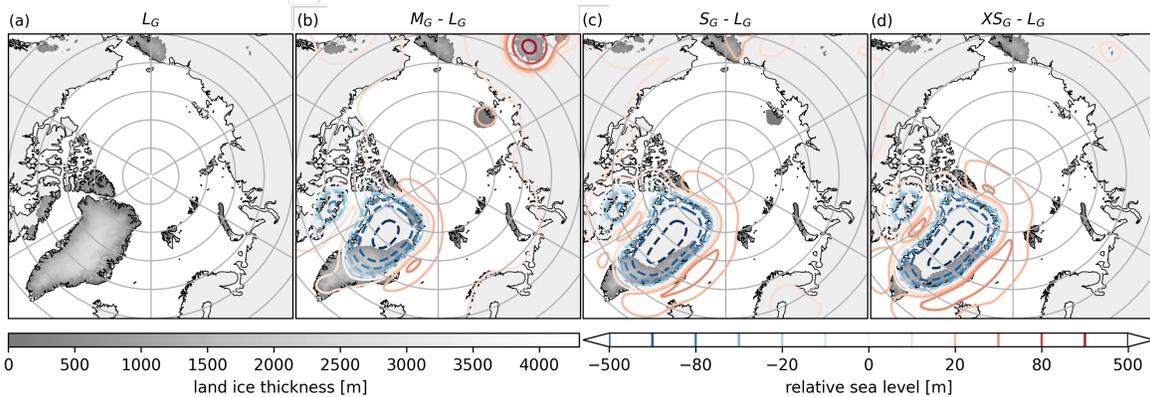

Figure 3: Effect of isostatic adjustment, shown as the relative sea level, and ice sheet thickness for each steady state. The left column displays the absolute values of L_G. The remaining columns show the difference in relative sea level of each state compared to L_G, depicted as colored contour lines, ranging from lower sea levels (blue) to higher sea levels (red). Gray filled contours show the ice-sheet thickness of each state.

L85–86: You talk of previous studies neglecting interactions with components such as the AMOC, vegetation, and isostatic adjustment. Since these interactions were previously neglected, it would strengthen the discussion (in Section 4 and perhaps already here) to comment briefly on whether they are important in your results—e.g., does the AMOC play a stabilizing or destabilizing role for any of the steady states?

We agree with your comment. In our manuscript, we explain that the AMOC contributes to the stabilization of the southern part of the XS GrIS (l.220-223). We have analyzed the variability of the AMOC and the SMB in XS_G and find a linear relationship with an increase of the SMB by $40.7\,\mathrm{mm}\,\mathrm{WE}$ per $1\,\mathrm{Sv}$ decrease of the AMOC strength. We added the following sentence to highlight the contribution of the AMOC: "A weaker AMOC strength at $30°\,\mathrm{N}$ in XS_G (*14.6* Sv) compared to L_G (17.3 Sv)

further reduces the northward heat transport, contributing to the colder upper ocean temperatures in the Nordic Seas. As the colder air is advected onto the GrIS by southeasterly near-surface winds (Fig. 4d), this cold ocean anomaly likely contributes to preserving the southern part of the very small ice sheet in XS_G. *Analyzing the variability of the AMOC and the SMB in XS_G, we find a linear relationship with an increase of the SMB by $40.7\,mm\,WE$ per $1\,Sv$ decrease of the AMOC strength."* We also find that the destabilization of M_G* coincides with a stronger AMOC (see our response to your previous comment).

As outlined in our response to your previous comment, we added a short analysis of the GIA feedback to the results section. Now, we also mention the contribution of regrowing vegetation more explicitly in the results section: "Another contribution arises from the smaller glacier mask and the absence of a snow cover in summer, which changes surface parameters to those of a non-glaciated surface. *The latter enables the dynamic growth of grass and shrubs in ice-free areas. These surface changes reduce the summer albedo by about 0.6, leading to a strongly positive melt-albedo feedback. They also allow surface temperatures to exceed the melting point in XS_G.* "

L95–96: "we identify which feedbacks or combination of feedbacks constrain each steady state of the GrIS." This is central to your paper's theme but remains somewhat implicit. A concise table summarizing which feedbacks constrain which state would help make this claim more concrete.

As mentioned in earlier comments, we added summarizing table to the results.

L127: "the asynchronous coupling method has no impact on the results." This phrasing feels too strong. Consider softening it to something like "We find no significant impact on the results or conclusions from the asynchronous coupling method."

Thanks. We added: *"Focusing on the equilibrated steady states, the asynchronous coupling method should have no significant impact on the results."*

L129–150 This paragraph is long and dense. Consider splitting it into smaller paragraphs to improve readability.

This is true. We split the paragraph into three separate paragraphs.

L130 "five simulations starting from different GrIS volumes (0%, 21%, 43%, 70%, and 100% of the PI value; Tab. 1)." The list of initial conditions does not match Table 1 (which lists 0%, 33%, 70%, 100%). This creates confusion. Either align the lists or move the table reference to where the consistent set appears.

Thanks for pointing this out. The values in the table refer to the simulations analyzed in the results section, which have been obtained from the combination of the baseline and threshold experiments. To not confuse the reader, we removed the first reference to the table and added a sentence in which we refer to the table after describing the experiments: *"The final steady state simulations and the sensitivity experiments are summarized in Table 1."*

L200–201: "the dynamic growth of grass and shrubs in the unglaciated areas, which leads to strongly positive melt-albedo feedback." Please clarify whether vegetation expansion is itself what you refer to as the melt-albedo feedback. Typically, the melt-albedo feedback refers to darkening of snow/ice by melt rather than vegetation. If the vegetation effect is distinct, please rephrase accordingly.

We rephrased this part accordingly: "Another contribution arises from the smaller glacier mask and the absence of a snow cover in summer, which changes surface parameters to those of a non-glaciated surface. *The latter enables the dynamic growth of grass and shrubs in ice-free areas. These surface changes reduce the summer albedo by about 0.6, leading to a strongly positive melt-albedo feedback. They also allow surface temperatures to exceed the melting point in XS_G.* "

L242–243: When describing how the SG state becomes unstable and transitions to the MG state (paraphrasing: Above a certain threshold it becomes unstable), consider mentioning which physical

processes cause this instability.

This is a good idea. We added the respective processes.

L290: You mention "the inertia of the ice sheet." Please clarify what is meant by "inertia." In a physical sense, ice sheets have relatively slow response times but limited true dynamical inertia; a short explanation would avoid confusion.

We revised this part accordingly: "[...] arises from the slow response time of the ice sheet due to which the AIS needs several [...]."

L342: "Below 70–68%, even further parts of the GrIS are lost". It is unclear where these threshold numbers (70 – 68%) come from. Please specify.

Unfortunately, an error occurred in this threshold. The correct threshold should be 43-33% based on Figure 2. We corrected the percentages accordingly.

L193: Suggest to revise to: "Only in the mountains are temperatures cold enough..."

We revised the sentence accordingly.

L263–264: Revise to: "does an ice cover in the northwest become stable"

Thanks, we revised the sentence.

L273:"disintegrates" (add final s)

Thanks for spotting this. We corrected the grammar.

Response to the comments of reviewer 2 for the manuscript "Stabilizing feedbacks allow for multiple states of the Greenland Ice Sheet in a fully coupled Earth System Model"

by M. Andernach, M.-L. Kapsch and U. Mikolajewicz

December 2025

We would like to thank the reviewer for the valuable comments and specifically for the suggestion to highlight the feedbacks that maintain the steady states. We have carefully considered the feedback provided and revised our manuscript accordingly.

We provide a detailed point-by-point reply to all comments below. The reviewers' 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 looking forward to your feedback.

Kind regards,
Malena Andernach, Marie-Luise Kapsch and Uwe Mikolajewicz

Response to reviewer 2

In this paper, Andernach et al. explore with an advanced fully coupled model potential multistable states of the Greenland Ice Sheet. The authors find four ice sheet steady states under pre-industrial greenhouse gas forcing, and illustrate ice-climate feedbacks and climate processes responsible for ice sheet regrowth or failure to regrow. Andernach et al. also illustrate that including an active Antarctic Ice Sheet in their model has an impact on the timing and magnitude of Greenland changes.

This paper represents a very nice contribution to the modelling community, particularly for those involved in coupled Earth system/ice sheet modelling efforts, and it's a great fit for The Cryosphere. I surely recommend publication, after some (minor) comments are dealt with. I have two general comments regarding the way methodology and results are presented, which I hope the authors will find useful. More detailed specific comments follow, suggesting changes that I hope will improve readability and clearness.

We are grateful for the overall positive feedback of our analysis of the impact of a disintegrated Greenland Ice Sheet (GrIS) on the atmosphere and ocean. We thank the reviewer for taking the time to review our manuscript.

General comments
1. I think that the section where ice sheet climate feedbacks are introduced is a bit hard to follow, and the paper would benefit from a more organized structure - perhaps where (a) first, all positive and negative feedback are introduced, and (b) then, the main studies illustrating the impact of these feedbacks are cited. Finally, it would be good to state clearly which processes and feedbacks are accounted for in your studies.

Thank you for your suggestion. We restructured this part of the introduction in a way that we first explain all the positive feedbacks, then discuss them and then continue with the negative feedbacks. We also added a clear statement to the methods section which processes and feedbacks are accounted

2. You mention that your model is coupled with a solid Earth model (VILMA), but there is no mention of how this coupling is affecting the results of your simulations. Maybe there is no large impact compared to other ice-climate feedback and processes, but it would be good to have some text dedicated to that. Similar for the vegetation - it would be very interesting to learn what's happening in ice-free Greenland, especially in regions where the ice sheet can't regrow.

The effect of the glacial isostatic adjustment is outweighed by the effect of the elevation difference due to the different ice sheet thicknesses. To be able to better separate and quantify the contribution of each feedback to maintain the steady states, we performed additional sensitivity experiments. We added a table of the feedback contributions to the results section (Tab. 1). We now also mention the contribution of each feedback in the text. Lastly, we added a figure showing the effect of the glacial isostatic adjustment (Fig. 1). The effect of vegetation is included in the contribution of the removal of the glacier mask. Unfortunately, it is difficult to separate the different effects that are involved when removing the glacier mask or parts of it: It includes changes in the surface temperature that can exceed the freezing point in absence of a glacier mask, changes in the surface albedo and dynamical growth of vegetation. However, we added information on the kind of surface cover or vegetation that grows in the regions without ice in Greenland.

	ice thickness	GIA	glacier mask	precipitation	ocean
$XS_G \rightarrow S_G$	++++	--	++	-	+
$S_G \rightarrow M_G$	++++	--	++	-	+
$M_G \rightarrow L_G$	++++	-	+++	+	-
$S_G \rightarrow XS_G$	----	++	--	+	-
$M_G \rightarrow S_G$	----	++	--	++	-
$L_G \rightarrow M_G$	---	+	--	+	+

Table 1: Contribution of the different feedbacks and processes between the GrIS and the climate system to stabilizing the steady states. The number of signs indicates the magnitude of the contribution of the respective factor to stabilizing (minus signs) or destabilizing (plus signs) a GrIS state. It is calculated as the spatially-averaged difference between the SMB field of each steady state and the SMB field of this state including the indicated feedback based on its neighboring GrIS state in Appendix B (e.g., SMB of XS_G minus the SMB calculated under the climate of XS_G but with the precipitation scaled to the precipitation field of S_G). The spatial averages are computed for the non-overlapping area between the two different glacier masks in central Greenland (solid and dashed lines in Appendix B), excluding scattered coastal grid cells. The upper half of the table shows the contributions for a transition from a smaller into a larger GrIS state and the bottom half of the table for a transition from a larger into a smaller GrIS state. The intervals used for scaling are: 0-50 mm WE yr^{-1} (regular-font minus), 50-249 mm WE yr^{-1} (bold-font minus sign), 250-749 mm WE yr^{-1} (two bold-font minus signs), 750-1499 mm WE yr^{-1} (three bold-font minus signs) and ¿1500 mm WE yr^{-1} (four bold-font minus signs) for negative feedbacks and mirrored for positive feedbacks indicated by plus signs. Note that *glacier mask* also includes the albedo feedback.
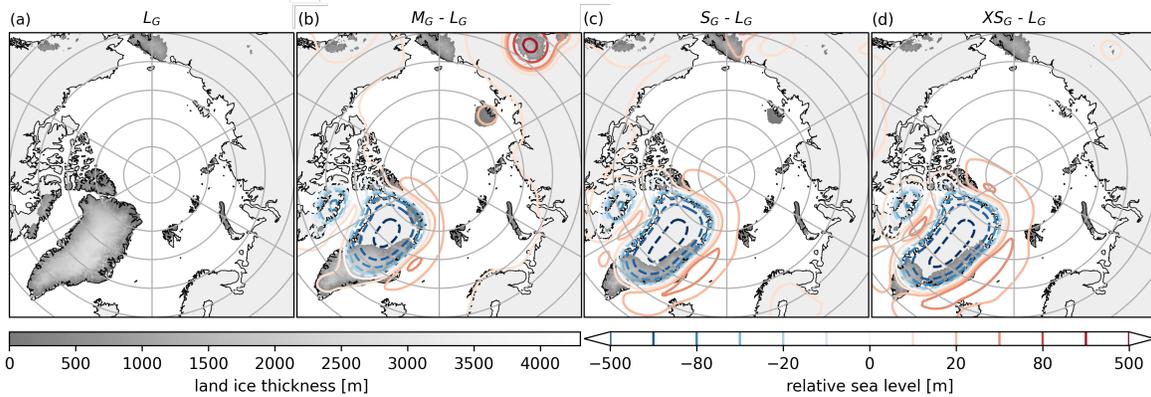
Figure 1: Effect of isostatic adjustment, shown as the relative sea level, and ice sheet thickness for each steady state. The left column displays the absolute values of L_G. The remaining columns show the difference in relative sea level of each state compared to L_G, depicted as colored contour lines, ranging from lower sea levels (blue) to higher sea levels (red). Gray filled contours show the ice-sheet thickness of each state.

Specific comments
Abstract
L2-3: I think the introduction should introduce the concept of multistability - maybe emphasizing that studies suggesting the existence of abrupt thresholds an no multistability often neglect important feedbacks (in contrast with Gregory et al. 2020).

Thanks for the suggestion. We added the concept of multistability to the beginning of the abstract: "*To date, it remains uncertain at which volume threshold the Greenland Ice Sheet (GrIS) mass loss will become irreversible under continuous warming and if the GrIS could regrow under pre-industrial (PI) CO_2 concentrations.*"

L4: Maybe mention explicitly that your model includes active GrIS and AIS?

We added "This model system is more complex, *includes interactive GrIS and Antarctic Ice Sheets (AIS)* and more critical feedbacks relevant for the stability of the GrIS than previously used models."

L4-5: Maybe provide some examples of what these feedbacks are?

Thanks you for the suggestion. Due to the word limit in the abstract, we would like to focus on the most important results in the abstract rather than describing the model more in depth. However, we included some information on the relative importance of the climate-ice sheet feedbacks based on our new sensitivity experiments.

L6: Not sure it is immediate for the reader what the GrIS PI state is... you mean an ice sheet state similar to a present-day state with PI climate?

L_G was initialized with a PI GrIS and run for more than 40,000 years. During this time, the ice sheet remains stable. Thus the final state is comparable to the PI GrIS state. The present-day state of the GrIS is similar to the PI state. We modified the formulation: "*A state with a large GrIS, similar to the PI and current state, [...].*"

Introduction

L23: When you mention sea level, I would also include a reference to the latest ISMIP paper for Greenland, Goelzer et al. 2020.

We added this reference.

3

L25: Some more recent papers simulating GrIS tipping point are Bochow et al. 2023 and Petrini et al. 2025. Might be worth mentioning those.

Good idea. We added these references.

L26-29: For clarity I would mention immediately that your ice sheet model coupling is bi-polar (also, it is a pretty cool feature!). Something like '...coupled to an ice sheet model (ISM) over Greenland and Antarctic domains...'. Also, I think you should mention here which are the models you are using.

Thanks for the suggestion. We reformulated this sentence and made clear that we employed a bi-hemispheric set-up: "To explore the stability of the GrIS and to understand the climate conditions that constrain potential multiple steady states of the GrIS, we take advantage of the newly developed Max Planck Institute for Meteorology Earth System Model (MPI-ESM) coupled to the modified Parallel Ice Sheet Model (mPISM) in a bi-hemispheric set-up and the glacial isostatic adjustment model VIscoelastic Lithosphere and MAntle model (VILMA, Mikolajewicz et al., 2025). The bi-hemispheric setup allows us to also investigate the role of the Antarctic Ice Sheet (AIS) for the stability of the GrIS."

L32: As in the abstract: I think it would be good to clearly introduce the concept of multistability (hence monostability) before the first mention.

The aim of this paragraph is to introduce the concept of multistability. To make it better understandable, we added a further explanation: "A full regrowth of the GrIS has been shown to be possible under present-day (PD) climate conditions due to a monostability of the GrIS in studies using a stand-alone ISM (Letréguilly et al., 1991; Lunt et al., 2004). Monostability means that a system (e.g., the GrIS) experiences only one stable state under the same climate conditions. It is in contrast to multistability, where a system can experience several stable states under the same climate conditions depending on its history. Such multistability has been shown in General Circulation Model (GCM) modeling studies, in which a disintegration of the GrIS would be irreversible [...]"

L35-36: Perhaps it would be good to quickly mention the complexity/resolution of GCM used in these studies.

The models used in these studies had a coarse resolution. In this paragraph, we do not want to focus on specifications of the models, but on potential states of the GrIS. Therefore, we prefer to not add too much detail on the specifications of the models. However, we added a short note that these GCMs had a coarse resolution.

L42-48: You don't mention the melt-albedo feedback here, and it's is a bit strange, since you mention it in the abstract. Also, might be worth mentioning precipitation changes due to orographic changes (see General comment 1).

Please see our response to your first general comment.

L52: Missing 'side'?

Thanks for spotting this. We corrected it to: "on the lee side".

L63: Maybe important to mention that glacial rebound operates on millennial timescales , as opposed to some of the ice-climate feedbacks mentioned above (see also Petrini et al. 2025).

Good idea. We added a sentence on the long time scales of the GIA feedback.

L64: Is instead of has? Or perhaps I am not understanding the phrasing.

Thanks for spotting this. We corrected the phrase accordingly.

L72-75: The sentence about ice sheet-ocean feedback in Antarctica feels a bit off-topic (and overly simplified) at this point, perhaps there is no need to mention it?

We would like to keep a short paragraph on the interactions between the AIS and the GrIS as it serves as a motivation to investigate the potential impact of the AIS on the GrIS steady states. However, we removed some of the information that is not needed to understand our results.

L88: ...one study of the stability of the GrIS exists that accounts accounts... . Also, I think that you should mention that the resolution of the model used in Vizcaino et al. 2008 is quite coarse.

Thanks for pointing this out. We added a short sentence on the coarse resolution of this study.

Methods

L104: Maybe add 'with a non-evolving Antarctic ice sheet'.

The steady state simulations were run with an interactive AIS. Only the sensitivity experiments used a constant AIS.

L113: ...was is calculated during runtime... I think that you should also add more detalils on how the SMB is downscaled in your model, considering that there is a large gap between atmospheric resolution (3deg) and ice sheet model resolution (10 km).

We revised the sentence. Further, we added more detail on the downscaling of the SMB: *"At the atmospheric boundary, the ESM and PISM are coupled through an energy balance model (EBM), which calculates a yearly SMB on 24 height levels based on hourly atmospheric data. This data is then interpolated onto the ice sheet surface (for details see Kapsch et al. 2021). At the ocean interface, salinity and temperature averages from 203 to 523 m are used to extrapolate the ocean conditions underneath the ice shelves and to estimate basal melt (Mikolajewicz et al., 2025)."*

L124: What happens with the freshwater fluxes at the end of the 100 years-long ISM cycle? Is the ocean receiving an averaged amount or an integrated amount of freshwater fluxes?

At the end of the 100 years-long ISM cycle, the volume change of the ice sheets is computed. This volume change is added to the ocean as an averaged amount of freshwater flux. We added a short note on this to the Methods.

L130: Again, how the PI value for GrIS volume and extent compares to the present-day value? Or PI = PD? Same for AIS at L134.

We added a sentence that the PI state of the GrIS and the AIS is similar to PD.

L140: Are you isostatically adjusting the bedrock also for intermediate volumes?

We added a short note that all our simulations include dynamic GIA.

L141: It's not clear how you obtained intermediate initial GrIS volumes: aren't all the simulations using constant PI GHGs concentration? Did you run your model at different CO2 concentrations to get the different initial states? For how long?

We obtained the initial volumes of the intermediate states from a simulation in which the GrIS regrew under decreasing CO_2 concentrations. We branched of equilibrium simulations at different points in the regrowth, which we continued under PI CO_2 concentrations. We added this explanation to the manuscript: *"We branched of simulations at different points in the regrowth (21%, 43% and 70% of PI volume), which we continued under PI CO_2 concentrations until reaching a new equilibrium."*

L149: I suggest to mention that S_G means small Greenland and XS_G means very small Greenland, in the same way M_G and L_G stand for medium and large Greenland. I see you do it at the beginning of subsection 3.1, but good to have it here too I think.

Thanks. We did this.

Results

L166: Missing m before SLE.

Thanks for spotting this.

F1: Based on the ice extent in L_g, it looks like there are several locations where Greenland is in contact with the ocean. It should be quickly clarified in the methodology section how marine-based ice is treated in Greenland and Antarctica.

Ice that is in contact which the ocean can be subjected to basal melt. As mentioned in one of our previous responses, we added a short description of the coupling to the Methods.

L174: Isn't the temperature shown in Fig. 3a and 3e DJF and JJA, respectively?

Yes, this is correct. We therefore added: "[...] *and a minimum temperature in winter of on average -26.7°C (Fig. 3a)"*.

L175-176: If the section is about Results only, it feels somehow strange to see results from other studies. A sentence like 'The high orography blocks synoptic storm systems approaching Greenland from the west (Andernach et al., 2025; Dethloff et al., 2004).' belongs perhaps more to section 4 Summary and Discussion? It may be personal preference though. If you want to present results and discuss them immediately, maybe better to have section 3 Results and Discussion and section 4 Summary?

In this study, we did not investigate the response of synoptic storm systems. However, we did so in a similar model setup in a previous study (Andernach et al. 2025). Therefore, we would like to refer to this study in the results without discussing this finding. This information rather serves to understand the regional climate conditions associated with a large GrIS.

L182-185: I would reference Figures to support these statements.

We reference the figures later in the paragraph. To support these statements, we moved the reference to this part of the text.

L196: Can you try to quantify this lapse rate effect?

Assuming a lapse rate as used in our EBM, we find a temperature effect of up to 10.6°C in the areas of the largest change in surface elevation. Thus, the lapse-rate effect has the strongest contribution to the annual-mean temperature change of up to 11.7°C in XS_G compared to L_G. We added this information to the results.

Fig4: Would it be possible to zoom a bit more the figure around Greenland like in Figure 3?

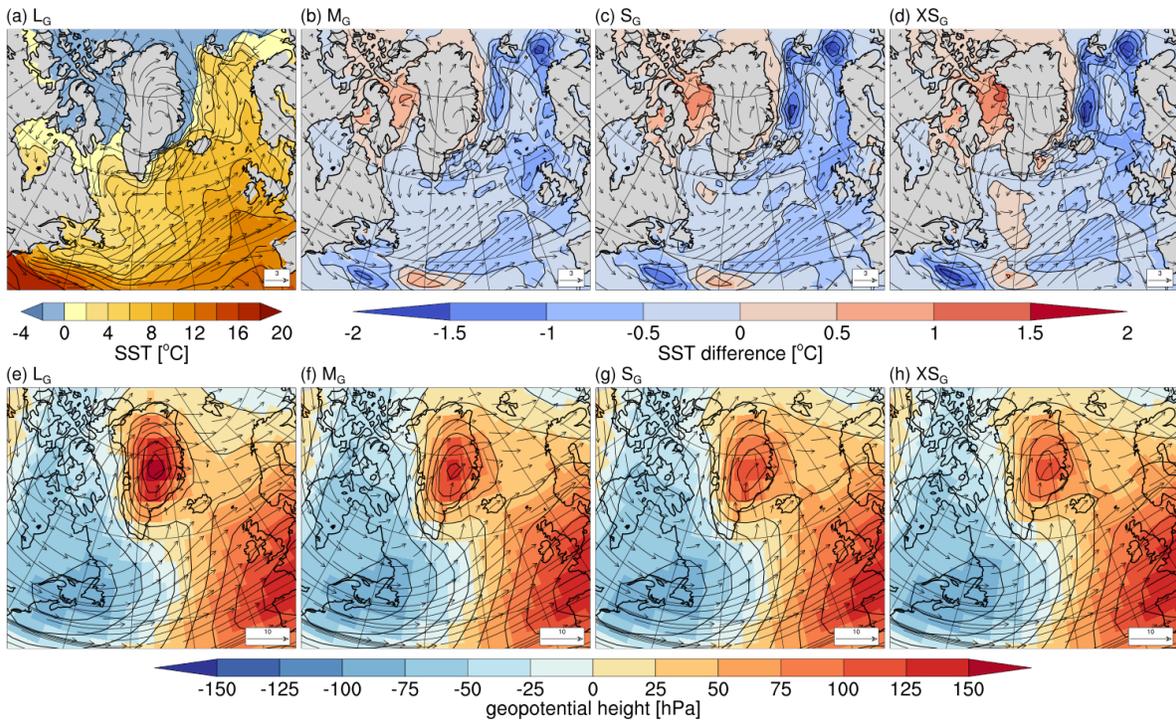Yes, we adjusted the map extent to be equivalent to Fig. 3 (see Fig. 2 below).

Figure 2: Modified Figure 4.

L237: Not sure about the use of 'reminiscent' here.

We agree and replaced it by "*originates*".

L251-252: This reminds me of what happens in Petrini et al. 2025 (although with shorter timescales of 20,000-30,000 years), where central west margin remains stable for about 20,000 years and then enters self-sustained retreat all the way to the east. See Fig. 2, simulation +3.4 K. This is interesting as simulations in Petrini et al. 2025 include melt-elevation feedback only, as there is no climate coupling.

Thanks for pointing this out. We associate the destabilization with the concurrent increase in the AMOC strength. The melting then becomes self-sustained due to positive feedbacks (i.e., melt-elevation and melt-albedo feedback). We now shortly discuss this similarity in the discussion section.

L276: Please include in the manuscript how you deal with ice-ocean interactions; I understand this is described elsewhere, but I think a paper should provide the essential information to the reader to be able to understand methodology and results.

We now provide some information on the coupling of the ocean and ice sheets in the Methods (please see also previous comment in the Methods section).

L281: I understand that the paper is about Greenland, but some more information or figures about the processes leading to WAIS collapse would be useful.

Thanks for your comment. In this paper, we focus on the steady states of the GrIS and how they are impacted by changes in the AIS. We agree that it would be interesting to also understand the exact mechanisms that lead to the collapse of the WAIS. However, this is out of the scope of this manuscript and is discussed in other papers (please see references in the manuscript).

L285: at $\tilde{3}$-degree resolution, is the ocean model 'seeing' that?

Yes, the ocean resolution is high enough to capture the opening of new ocean passages. Meccia

and Mikolajewicz, 2018 provide information on the sophisticated tool that is used to automatically compute bathymetry and land-sea mask changes in response to freshwater and bedrock changes in MPI-ESM.

L299: same comment as before about Results/Discussions.

We agree with your comment and moved this comparison into the discussion.

Summary & Discussion

L349: I am not sure about the relevance of this sentence, as the paper here explores very idealized scenarios and very long timescales.

It is true. Our scenarios are idealized and explore long time scales. However, we would still like to point out that a partial or complete loss of the GrIS in the long term would have major consequences for our society.

L350: Are you referring here to model uncertainty?

*No, we refer to the different thresholds that have been found previously with simplified or uncoupled models. We modified the sentence to: "*Diverging temperature thresholds for the full recovery of the GrIS have been found *and the [...]"*

L364-366: I would remove 'including climate-ice sheet feedback' to improve readability, I think it's clear at this point in the manuscript that your simulations are doing that.

We would like to keep this part of the sentence as it highlights the main difference of our study to previous studies.

L371: While I can intuitively understand what the authors mean with 'topographic pinning point', it may be necessary to give a clearer explanation to facilitate the reader.

We now explain the term better: "This expansion is further constrained by the absence of topographic pinning points, which could serve as seeding points for ice sheet regrowth over *flat terrain and in the lee of the GrIS."*

Conclusions

L424: Maybe add main drivers of this multistability?

Thanks for the suggestion. We reorganized this section and added a conclusion on the contributions of the different feedbacks.

L427: This sentence is a bit vague; of course, it is important to include all feedbacks, but can you mention which are the most important in your simulations?

Please see the comment above.

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