Authors final response to Niall Gandy (RC2)
TC-2022-215

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The authors are deeply grateful for the elaborated and constructive comments of the reviewer. This work will firmly benefit from them. We have responded to all comments below. Reviewer's comments are given in blue font whereas the author response reads in black.

Summary

Moreno et al. present a series of simulations of the North American Ice Sheets, exploring the resulting ice sheet volume, area, and velocity pattern from varying the ice sheet sliding law. While the results show only limited variation in the ice sheet volume and area, the ice sheet velocity pattern is sensitive to the sliding law used.

This manuscript is well presented, with clear text and figures. Most importantly, the work as been clearly and comprehensively described, and the results are presented and discussed in good detail. I recommend that the manuscript is published following minor corrections/clarifications (detailed below).

I hope you have a good Christmas break, and I hope to reading a revised or published version of the manuscript in the new year.

General Comments

A direct visual comparison between the ice stream dataset from Margold et al and your results here would be useful. Essentially, it saves the reader flicking between browser tabs,

and I expect it would show clearly the match you have described in the text. Within this it would be good to discuss the potentially transient nature of some ice streams, and how this might effect the empirical mapping, your modelling results, and the comparison between the two.

Margold et al. (2015) data is not publicly available. A visual comparison with previous LIS reconstructions is already provided in all 2D plots by the ice-sheet extent taken from ICE6G (Peltier et al., 2015). Particularly, Margold et al. (2015) provided with an ice stream inventory from geological reconstructions and does not allow for a quantitative comparison as such. Available information about individual ice streams of the Laurentide Ice Sheet can be found in the Supplementary material of Margold et al. (2015).

I think it is reasonable that you have run your simulations to equilibrium, but it will probably have an effect on your results, given ice stream sensitivity to climate forcing. This should be discussed in the text.

Indeed, transient simulations may have an impact given ice stream sensitivity, though minor implications on the results of the present work. We must keep in mind that we are comparing our ice streams to prior inventories (e.g., Margold et al., 2015). It is clear that their mapped ice stream tracks represent a time-transgressive imprint of evolving ice stream trajectories, i.e. they can not have all operated at once. Nonetheless, some broad spatial patterns appear and we further exploit this fact to compare our simulations. Potential timing inconsistencies are thus inevitable, though the time-transgressive inventory remains as an appropriate reference for the simulated ice streams.

The discussion section have been expanded to account for this simplification and transient simulations are in fact in the scope for future work.

Minor points

- Title: While I would often refer to the ice simulated here as the "Laurentide", more formally I would opt for "North American Ice Sheets". Laurentide is neater, North American Ice Sheets is clearer. If you stick with Laurentide consider a very brief mention in the Introduction.

  We have kept "Laurentide" in our title, though we have included a brief clarification on our terminology in the introduction. We thank the reviewer for this comment.

- Ln 25: "Strictly speaking"... This sentence isn't clear to me, please rephrase

  This statement has been rephrased.

- Ln 28: References for the initial assertion? Perhaps Calov et al., 2002, Tarasov and Peltier, 2004, or others?

  We have included additional references. We thank the reviewer.

- Ln 36: Extension > extent – and other uses later in the manuscript

  This has been fixed throughout the text.

- Ln 36: "largely differ" > "differ largely"

  The manuscript has been corrected accordingly.

- Ln 44: If the variable ice thickness is through a surging/instability mechanism say this explicitly. This paragraphs touches on the idea that ice stream instabilities could significantly influence the ice sheet configuration, but more detail/references would be appreciated.

  Additional references have been included upon the idea that ice streams instabilities could influence the ice sheet configuration.

- Ln 71: Please provide some further justification for these parameter values.

  In the current study, the enhancement factor is treated as a tuning parameter. Laboratory experiments provide the basis for estimating such parameter (e.g., Russell-Head and Budd, 1979; Baker, 1981,1982). More recently, Budd and Jacka (1989) and Jacka and Maccagnan (1984) have suggested enhancement factors up to 3. We employ typical values found in Ma et al. (2010). An example of spanned parameter range can be found in ISMIP6 (Seroussi et al., 2020).

- Ln 95: It's pretty typical to ignore horizontal water transport, but not always (e.g. Gowan et al., 2018). It's worth justifying this simplification.

  Considering horizontal advection is indeed a more sophisticated description. However, our simplification is justified since we assumed till properties similar to Tulaczyk et al. (2000). The hydraulic diffusion coefficient shares the same order of magnitude $c_v \sim 10^{-8}\ m^2/s$, hence horizontal advection becomes negligible compared to the local basal mass balance.

- Ln 104: What happens to excess water beyond the 2 m limit? Does it accumulate but is ignored, or disappear?

  This is in fact one of the caveats of the local non-conserving approach. Once the 2 m limit is reached, any additional water production disappears. Water is therefore not strictly conserved. A better representation of subglacial hydrology is in the scope of future work.

- Ln 173: By averaging 11 PMIP simulations you remove the consistent climatology provided by a single model. Is this important?

In this study, we want constant boundary conditions rather than a time-dependent forcing for our simulations. Thus, taking the average among climatologies gives us a more robust boundary condition and smoothes potential peculiarities of each General Circulation Model.

Particularly, some authors have argued that: *"Just as the mean of n uncorrelated random variables with variance 1 should have variance* $1/n$*, we should expect that the ensemble mean of independent models defined in this way would (a) perform better than any individual simulation, and (b) asymptotically converge to zero error as the size of the ensemble of independent models (with zero error correlation) increases."* (Abramowitz et al., 2018).

If we were to study transient behaviour, consistent climatologies provided by each model should be considered independently.

- Ln 173: Are all 11 PMIP simulations using the same ice sheet reconstruction?

  Yes, as described in their experimental design (`https://pmip3.lsce.ipsl.fr/`), the ice sheet extent and related changes in topography is prescribed and provided for the *21 ka - Last Glacial Maximum experiment* (see PMIP 3-CMIP 5 Experimental Design).

- Ln 196: As your climate forcing in Figure 1a and b inherently contains a previous ice sheet reconstruction which broadly matches the empirical reconstruction, how surprising is it that your simulated extents are okay?

  Whilst ice extent is implicitly contained in our climatic forcing, the simulated LIS extension is still highly sensitive to the ice-sheeet model parameter choice. In the end it is a question of surface mass balance, determined by the climatology and affected by the extent (and more notably the elevation) and dynamics, which are very much dependent on model parameters. For the same climatic forcing, we could obtain an ice sheet that would largely differ from prior reconstructions solely by employing a different parameter space. The interesting result is that we did not tune our model to match a certain volume/extent value, but rather to develop an ice stream network comparable with existing inventories.

  Moreover, in order to avoid any inertia of the model to evolve towards the inherent previous ice extent, we further apply a lapse rate factor correction of the temperature and precipitation PMIP3 forcing fields as a function of the local surface elevation.

- Figure 2: It would be good to see a direct visual comparison to the Margold ice stream reconstruction. It would also like to see one section of the ice sheet in more detail to show the nature of ice streaming at the margin. Maybe there could be a separate plot of the Hudson Bay and surrounding ice streams?

  The main focus of the present work is on the general ice stream network configuration of the LIS rather than on certain located areas. Nevertheless, following the comment made on Line 256, we have expanded Table 2 so as to account for equilibrium fluxes and mean/min/stdev velocities. Additionally, there is a new figure (Fig. 11) that

complements the description in the text and captures the changes in the probability density function of the basal temperature and the sliding velocity.

- Ln 256: A table summarising key statistics of Linear, plastic, and coulomb simulations might be helpful to compliment to description in the text. A quick lookup for the equilibrium fluxes, mean/min/stdev velocities would be appreciated, perhaps an extension to Table 2?

  We have included an extension to Table 2 with equilibrium fluxes and mean/min/stdev velocities as a complement the description in the manuscript. Moreover, we have included an additional figure (Fig. 11) that complements the description in the text and captures the changes in the probability density function of the basal temperature and the sliding velocity.

- Ln 275: Quantitative or Qualitative?

  Qualitative. This typo has been fixed.

- Figure 6: This is a very useful figure. There seems to be an edge effect stripe in panel b and c (around 100m Hice). Do you know what is causing this?

  It is presumably a consequence of the minimum ice thickness considered by the model. For these simulations, we set such value at 100 metres, so that a grid cell with a smaller amount of ice is neglected in the following time step.

- Figure 7: This figure is good at showing the model's behaviour in general, but the visual comparison between sliding laws is tricky? Perhaps you could experiment with plotting curves from multiple simulations on the same panel.

  We first plotted multiple simulations in the same panel, yet it worsened the visualization as certain lines are quite close to each other. We thank the reviewer for this comment.

- Ln 341: ICE-6G

  This typo has been fixed.

- Ln 410: Where will the data from the simulations be available?

  Data will be stored in a Zenodo repository.