Response to Reviewer #2

J.A. Wilner et al.

August 11, 2023

SUMMARY

Wilner and colleagues assess how accurately four calving laws represent ten Antarctic ice shelves under the assumption that the ice front of these ice shelves are in steady state. For this purpose, they use a state-of-the art ice sheet model run at high resolution in constrained Antarctic domains. The metric they use to quantify the realism of the calving laws is based on the areal mismatch. Their results show that the eigencalving law (EC) and the von Mises law (VM) are the ones which best reproduce the calving front position. A further analysis based on the passive shelf ice (PSI) suggests that the VM law represents more accurately the observed PSI computed by Fürst et al., (2016). This manuscript is very well written and illustrated and it is very well suited for the scope of The Cryosphere. I do not have major concerns but I think some initialisation steps should be clarified for the reader. I also have some questions and suggestions for the authors which they may consider or not.

Response: We express our gratitude to the reviewer for the positive words and insightful feedback. Our responses to specific comments are presented below for your reference.

General comments

Initialization

I agree with the other reviewer that some important information is lacking in the methodology, mainly if basal melting is considered and how you treat grounded ice in your ice-sheet model. Is the grounding line fixed or is it allowed to evolve?

Response: As addressed in our response to the other reviewer, basal melting is incorporated via the dataset of Rignot et al. (2013). Some grounded ice adjacent to the floating ice is included in the overall model domain. Although the grounding line is allowed to evolve (which we will now specify in the manuscript), grounding line position is largely unchanged over the 200 year simulation for all benchmark ice shelves.

Ice shelf rigidity

You say that you invert for rigidity in ice shelves. Which parameter are you tuning there? The ice viscosity parameter B? A viscosity enhancement factor for ice shelves?

Response: We tune the ice viscosity parameter B, which we will now specify in the manuscript.

Stationary calving front position

As suggested by the other reviewer you could do an additional equilibration simulation with a stationary calving front position fixed to observations. You could compare there for instance the calving rate at the ice front for different calving laws with Rignot et al., (2013).

Response: Please refer to our response to the other reviewer in which we provide an equilibration simulation with a stationary calving front for Ross Ice Shelf. We will include a supplementary figure showing such equilibration results for each ice shelf.

von Mises calving law

One of the key messages of this manuscript is that the VM law best reproduces the observed calving front positions. However, as you state in the manuscript, this result can be partially explained by the fact that you invert for rigidity which is explicitly considered in the VM computation (Eq. 3). There exist other approaches in the literature for tuning ice shelves, for instance through enhancement factor (Surawy-Stepney, 2023) or basal-melting rates (Lipscomb et al., 2021), though the latter are applied to match observed ice thickness rather than velocities. Do you think that if you would have adopted another inversion method you would still have such a good ice front position with VM?

Response: Because σ_{max} is tuned, changing B would lead to a change in σ_{max} in order to get the same calving rate. Inverting for the enhancement factor would have a similar effect as inverting for B, or for the rate factor A. Regarding the question about adopting a different inversion method, it is indeed an interesting avenue for future research. Exploring alternative inversion techniques could provide valuable insights into the robustness of the VM law's performance in reproducing ice front positions, as well as the effectiveness of other calving laws. We will carefully consider such a question in the revised discussion.

Calibration parameter of von Mises calving law

You calibration parameter in the VM calving law is the tensile stress threshold σ_{max}. This threshold should represent a physical property of the ice, mainly the ice tensile strength (0.7 MPa; Morlighem et al., 2016, Bassis et al., 2021). Your obtained calibration values are lower, but in the same order of magnitude. Do you have an explanation or interpretation for this?

Response: Thank you for bringing this to our attention. We caution that VM remains a simple parameterization and differences in calibration values between different ice masses are not entirely unexpected given such factors as damage that weakens the ice, lowering its strength. This is just one possible interpretation.

Technical questions

- It is not clear to me how you apply calving in your ice-sheet model. Is the calving rate a thinning rate applied to the ice front or do you trace the ice front position via a level-set method?
  Response: We use the level-set method, and will clarify this in the text.
- The crevasse depth law (CD) is only computed at the ice front or are crevasses computed over the whole ice shelf? Do crevasses affect your ice dynamics?
  Response: The CD law is computed over the entire ice shelf, but is only numerically meaningful near the ice shelf front where the zero contour of the level-set is advected. As crevasses are not explicitly included in the ice flow simulation (their hypothetical depths are implicitly calculated in Equations 5-9 based on a variety of associated parameter values), crevasses do not affect ice dynamics here.
- How well do you simulate ice thickness with observations?
  Response: We use observations to initialize ice thickness, and the drift in ice thickness over the course of the simulation with a fixed front will be included in the supplement.