Summary and comments on the manuscript tc-2023-86 entitled

Evaluation of four calving laws for Antarctic ice shelves

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by

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SUMMARY

With this manuscript, the authors aim to put the applicability of four calving laws to the test for ten ice-shelf settings in Antarctica. For this purpose, they employ a state-of-the-art ice-flow model, which comprises accurate calving front tracking. For each ice shelf, the model is initialised with present-day maps of ice geometry and surface velocities. Consecutive forward simulations are undertaken for 200 years with constant climatic conditions. Assuming that present-day ice-front positions are in steady state, the authors then compare the final geometry with the observed calving-front positions. The areal mismatch serves as a quality measure. Results suggest that the performance of the *von Mises* laws and the *eigen-calving* are comparable. The former seem superior with regard to a buttressing analysis, because are larger fraction of passive shelf ice (PSI) is preserved - more comparable to observations.

The manuscript is very well written and illustrated and therefore easy to follow. The authors also formulate very concise objectives. However, I miss some important details of the experimental setup, which might well have implications for the interpretation of the result. Do not misunderstand me, I remain very positive about this manuscript and I recommend that the editor should continue to considered it for publication in *The Cryosphere* after my concerns have been alleviated. These concerns certainly imply a major revision.

MAJOR COMMENTS

EXPERIMENTAL SETUP

The introductory paragraph to section 2 (L102-117) serves to explain the experimental setup. Yet key information is missing here. As I understand it, your model domain only comprises the floating part of the benchmark ice shelves. I immediately wonder about upstream boundary conditions at the grounding line. I suspect observed velocities. For reproducibility, please specify the time period of the constant RACMO forcing. Finally, I wonder about your treatment of sub-shelf melting. This component is key to keep the ice-shelf geometry in balance/close to present-day. Yet the basal mass balance is unspecified. Please amend.

INITIALISATION

I understand that inverse techniques are used to get an initial model state from observations on ice geometry and surface velocities. After such an initialisation, there is no guarantee that subsequent simulations do not strongly drift away from these initial states (spurious flux-divergence, etc.). Even if such simulations would equilibrate after 200 years, the ice-shelf settings might be very different. Unfortunately the authors show no temporal evolution or quantify the overall mismatch between observed and modelled quantities of ice velocities, thickness or grounding line positions. Did you check if the volume evolution actually equilibrated or is there still a drift or some oscillations after 200 years. An additional equilibration simulation with a stationary calving front position, prescribed from observations, could prove useful. In absence of such reference information, it is very difficult to assess your calving-law analysis.

BUTTRESSING

I did enjoy reading the sections on buttressing and more specifically on the passive shelf-ice analysis. I consider it an interesting addition. Yet I am not convinced about your decision to presented it in the discussion section. Please consider transferring it to the results. Moreover, you are certainly aware that this analysis stays highly qualitative. In a way, I think it mostly boils down again to your areal analysis. Admittedly, there are some differences in the butteressing fields between the various steady-state geometries (Fig. 7) - also some distance usptream of the calving front. This difference might, however, be indicative for important differences in ice geometry and/or velocity impeding a clean comparison. Please check. Finally, the locally derived buttressing number from Fürst et al. (2016) has been challenged as an appropriate indicator for grounding-line buttressing (e.g., Zhang et al., 2020). You should pick this up in your discussion.

DISCUSSION

You start your discussion by a qualitative assessment of the EC and VM formulations and consequences on the expected frontal shapes. I am not sure if I fully follow your argument for the ‘evened out’ VM calving fronts (L258). In Fig. 3b and 4c, the VM law results in some elongated ice-shelf protrusions. In a latter section (L304-314), you expand this assessment to the anticipated frontal retreat under climate warming, which might less well be captured by EC. This is nicely substantiated by the results from Choi et al. (2018) on Greenland. I would transfer this section to the beginning of the discussion - just after your first explanations. I also appreciate your discussion of the computation of the areal mismatch - it is valuable. However, I completely miss any assessment of the experimental setup, involving model initialisation, calibration and equilibration. I wonder if you can compare the calibrated parameters (Table 1) to realistic ranges or values from other studies. As climatic conditions over Antarctica are not in steady state, also the assumption that the observed calving front should be reproduced in your model setup can be challenged. Please extend your discussion.

MINOR COMMENTS

L1 Insert ‘for each ice-shelf setup’ after ‘[...] of these calving laws’.
L222-224 Does your model see a pinning point beneath the Eastern section of the Thwaites Ice Shelf? If not, you might want to introduce some friction there. It would be good to include a supplementary figure on how modelled and observed velocity fields (and/or geometries along a flow-line) compare right after the inversions. Best for all ice-shelves.

FIGURES
Fig. 1 - 4 Can you specify if you show modelled or observed velocities as background field. I guess that Fig. 1 shows modelled results, while the others show observations. Which radar image (from which mission/sensor) is shown as grey shading.

Fig. 6 As it stands, this figure allows us only to compare PSI fractions for two calving laws. To me, it seems not possible to judge, which one is more reliable. I therefore suggest that you add the PSI fraction right after the model initialisation (t=0yr). This is not difficult and would give a baseline for comparison. As this plot aggregates information from all ten ice-shelves, I suggest that you further add a supplementary figure, which presents this PSI analysis for each ice-shelf. This might substantiate your argument why to prefer VM over EC.

REFERENCES

Fürst, J. J., Durand, G., Gillet-Chaulet, F., Tavard, L., Rankl, M., Braun, M., and Gagliardini, O.: The safety band of Antarctic ice shelves, Nature Climate Change, 6, 479, 2016.

Choi, Y., Morlighem, M., Wood, M., and Bondzio, J. H.: Comparison of four calving laws to model Greenland outlet glaciers, The385 Cryosphere, 12, 3735{3746, 2018.

Zhang, T., Price, S. F., Hoffman, M. J., Perego, M., and Asay-Davis, X.: Diagnosing the sensitivity of grounding-line flux to changes in sub-ice-shelf melting, The Cryosphere, 14, 3407{3424, 2020.