Review of "Sensitivity of the Ross Ice Shelf to environmental and glaciological controls" by Baldacchino et al.

General comments

The region of Ross Ice Shelf (Antarctica) is presently stable but basal melt rates might increase more and more in the future, leading to potential important mass loss of the ice shelf, and subsequent acceleration of its tributary glaciers. In this paper, the authors propose to map the regions of high sensitivity of the RIS basin to potential changes in ice rigidity and basal friction (glaciological controls), as well as surface mass balance and basal melting (environmental controls). For that, they use an Automatic Differentiation (AD) method, coupled to a 20-year simulation of RIS evolution under current forcings, using the Shallow-Shelf Approximation of the Ice-sheet and Sea-level System Model (ISSM). The AD allows to compute the gradient of the Volume of ice Above Floatation (VAF) with respect to the four parameters, and therefore the effect of a small perturbation in a parameter on the VAF (which is a good proxy to quantify the final effect of ice mass change on sea level rise). They conclude that the sensitivity to friction and ice rigidity is the higher at the grounding line and at glaciers and ice stream shear margins (with geographical variations). They also find, similarly to other studies (using different methods), that the sensitivity to basal melt changes is maximal at the grounding line.

The paper is relatively similar to Morlighem et al. (2021): Mapping the Sensitivity of the Amundsen Sea Embayment to Changes in External Forcings Using Automatic Differentiation, 2021). The authors used the same methods (2 co-authors are also on the 2021 paper) but on another region. As expected, the conclusions of the study are similar: the sensitivity to basal friction and ice rigidity is the stronger over the shear margins and upstream the grounding line. In this regard, little new insights are brought. However, in my opinion, the AD used by the authors is a powerful method that is still underused in the ice sheet community. Overall, this is an interesting work which can help in deciding what physical mechanism we should work on for better projections of the evolution of the region. It could also help in targeting regions to monitor when collecting observations.

Reading the results, I was wondering how different the sensitivity maps would be if (1) the forcings were different, (2) if the time period was longer (100 years for example), and (3) if the inverted friction/ice rigidity were different. If the results are sensitive to the simulation parameters and time, then, it should be discussed (see my specific comments below). If not, I think it would be worth mentioning. This could also be a great additional value with respect to Morlighem et al. (2021). Even without looking at longer simulations, I think that there was not enough results and discussion on the inversion and the 20-year simulation itself. Adding some details about it (as a supplementary material or as an Appendix) would be very valuable.

I found the comparison of the results with other papers (using totally other methods or based on observations) really interesting. I however want to point out that the discussion would benefit from being reorganized and a better writing. In general, I was slightly disappointed by the grammar and punctuation. Some sentences are poorly written and tend to decrease the readability of the paper (even in the abstract, see my technical comments).

Regardless of my concerns, and even though the method and the conclusions of the paper are very similar to Morlighem et al. (2021), I think that the relative novelty of the method and the appropriate comparison/discussion of the results with respect to other studies make the paper interesting and worthy of publication (after revision) and will be useful to the community.

Specific comments

- The Automatic Differentiation method used is a powerful tool but I would be careful concerning the conclusions about the sensitivity of the model to the ice rigidity change over the ice shelf. Non-linear effect aside, we could expect that a change in rigidity (let's say halving B) in a given area would lead to an important velocity change (about doubling the velocity). If such flow speed on the ice shelf was lasting longer than 20 years, it would eventually lead to a strong increase in flow from grounded ice (as the buttressing effect of the ice shelf would decrease as the ice shelf thins) and potentially subsequent VAF change. I agree that the authors clearly state that the map is the resulting sensitivity for a 20-year simulation but I think that, if you agree with my comment, it would be great to emphasis this in discussion/conclusions (similarly to what you have said for upstream ice at line 125).
- I guess that the method is also sensitive to the values of the initial parameters. The problem you solve is ill-posed by nature, which is a common problem in glaciology. During the inversion process, an underestimation of the friction can be compensated by a higher ice rigidity. How does it affect the sensitivity analysis?
- Figure 6: What is the cause of the high spikes downstream the grounding line? For SMB, this is a bit counter-intuitive given the conclusion of the sensitivity of the model to SMB changes on the ice shelf.
- Discussion:
    - While containing interesting ideas and developments (especially the numerous relations with other studies), the discussion would benefit from more structure. At the moment, ideas are a bit scattered and it is difficult to follow everything and have a proper appreciation of the results. You start with a discussion on the effect of friction, then ice rigidity before switching to SMB and basal melt rate, to come back to basal friction and rigidity. Please consider reorganizing the discussion.
    - Lines 155-165: Could you explain what is the difference between the grounding zones of the Bindschadler and MacAyeal Ice Streams and the grounding line of the Whillans Ice Stream? A few lines after, you talk about grounding line for the three ice streams.
    - Line 161: *"This stiffer till at the grounding line thickens the ice and stabilizes the position of the grounding line".* This statement is a bit misleading. If I understand correctly the mechanism, please consider adding something like *"the stiffer till creates more basal drag and therefore a slowdown of the ice, leading to an ice thickening"* or something similar.
- The conclusion is an example of an extensive used of conjunction adverbs: however, finally, therefore, thus. I think that in general, you could delete some of these conjunctions. It could also be broken down in two paragraphs.

- Similarly, “Additionally”, “in addition” or “therefore” is sometimes used twice in the same paragraph.

Technical comments

- Line 9-11: I found this sentence very long and maybe containing unnecessary details for an abstract. It also seems to me that it lacks a verb (?). Could you reformulate it? Maybe consider only mentioning “pinning points, larger islands, and the shear margins” instead of naming all the places.
- Line 23: consider changing *“[…] has been through ocean-forced basal melting”* to *“[…] has occurred through ocean-forced basal melting”*
- Line 30: I understand you statement about the sea level rise potential but I think that this sentence is not very clear, consider: *“These catchments, almost entirely buttressed by RIS, represent a total potential sea level rise contribution of 11.6 m“*.
- Line 44: maybe change *“at Ross Island”* for *“close to Ross Island*” (Ross Island being the grounded ice).
- Line 49: In Stewart et al. (2019), this statement is more of an outlook, as their work focuses on in-situ observations close to Ross Island. I might be wrong here but I don’t think that Schodlok et al. (2016) made projections, as they focus on the comparison between observations and simulations (past and present). You might want to cite papers about projections of future basal melt rates.
- Line 57: I think you should use a comparative (larger) and not a superlative (largest)
- Line 66: delete *“here”*
- Line: 68: Could you precise what temperature field you have used? Maybe also add which sub-element scheme you used (as you mention it).
- Line 85: I am not sure to understand here. I think you mean that a 20-year forward simulation (forced by SMB and basal melt rates outputs) **IS** used in the AD package (instead of **ARE**, which would refer to the forcings).
- Line 89: Please be more specific than *“overall ice viscosity”.*
- Figure 2: It might be interesting to use a logscale colorbar here. Right know it is relatively hard to make the distinction between the higher values (dark blue) and lower (but non-null) values (light blue). Could you also use non-italic font for the units?
- Line 106: change *“[…] sensitivity of the model with respect to […]”* for *“[…] sensitivity of the model to the basal friction […]”*
- Line 107: delete *“vast*”
- Line 113: *“Increase**s**”* instead of *“increase”*
- Line 119: add a comma between *“[…] ice rigidity”* and *“highlighting […]”*
- Line 125: add a comma between *“[…] over 20 years”* and *“therefore […]”*
- Line 132: What do you mean by *“grounding zones of the Siple Coast Ice Streams”*? To me the maximum sensitivity is much more inland, as you mentioned it before. Are you talking about the grounding zone as the surrounding of the grounding line? In this case, it does not look like the region with the highest sensitivity (maybe change the color bar so that it is visible in your Figure).
- Figure 5(a) is largely saturated, could you use a different color scale. Maybe with more than one color?

- Line 135: This statement is a bit misleading. The pinning points are very sensitive to SMB changes because they are part of the VAF. You already mentioned this for the grounded ice. You might delete this statement or put it after the statement *"This is expected since floating ice does not contribute directly to VAF".*
- Line 149: Delete the parenthesis *"(i.e., red outline in 5 showing the 'passive' ice region)"*. Passive ice has not been introduced yet in the text.
- Line 163: To me, it is the softening of the till that leads to a basal friction change (as perceived by the model) and not the opposite. You might consider rephrasing this sentence the other way.
- Line 165: consider a new paragraph here, as you transition from a focus on the basal drag to a focus on the ice rigidity.
- Line 165: similarly, here I think you should talk about "basal friction" instead of "till conditions".
- Line 168: *"Therefore, changes in ice rigidity at the grounding zones of the Siple Coast Ice Streams ~~changes~~ affect the ice flow and the discharge rates, which impact~~s~~ the overall mass balance of the RIS domain, as shown by our results."* This sentence clearly lacks punctuation (see my attempt of correction).
- Line 182: I think that your results show the opposite. In Figure 4, Bindschadler Ice Stream shows a high sensitivity to basal friction in the center of the stream. The high sensitivity at the margins is observed for the ice rigidity, or is there a mistake in the Figure labelling?
- Line 193: This is where, I think, you need another color scale on Figure 5.
- Line 197: It is only now that I really understand your statement at line 132. I think you need to be clearer at line 132 when talking about the high sensitivity of the grounding zone.
- Line 200: I am not sure that "promote ice thickness" is really what you want to say, maybe only "modify" or "affect". For example: "[…] would affect ice thickness and discharge on the RIS"
- Line 206: Maybe I am misunderstanding but the effect of the ocean heat on the ice temperature and the rate of basal melting is not really accounted for in the model, right? You apply the melt as a forcing with no feedback. It would be nice to specify this here.
- Line 212: would have greatest impact (compared to what?) on the final VAF if what? If basal melting was increasing in the future?
- Line 265: You write: *"These results show that the RIS mass balance is highly sensitive to changes in ocean circulation and mixing as well as tidal currents which could potentially drive changes in basal melt rates at the calving front at the grounding zones."* I guess you mean "at the calving front **AND** ant the grounding zones"?
- Line 268: I would delete the end of the sentence "*as this study identifies that these regions are important for the mass balance of the RIS*" as you already explained these two sentences earlier.
- Line 269: I agree with you. Such modeling can be useful to plan field campaigns. We do not use enough this kind of tool.