

## **Review of manuscript ‘Proglacial lakes substantially modulate the surface mass balance of deglacial ice sheets’ by Sijbrandij et al.**

The manuscript ‘Proglacial lakes substantially modulate the surface mass balance of deglacial ice sheets’ by Sijbrandij et al. presents an idealised numerical modelling experiment that attempts to quantify how large proglacial lakes can affect ice sheet mass balance through climatic processes for two former Northern Hemisphere ice sheets at the end of the Allerød Interstadial. As the authors highlight, there has been a recent trend of ice sheet modelling simulations that attempt to integrate an evolving proglacial lake layer and highlighting the importance of glacial lakes in forcing dynamic ice mass loss and rapid margin retreat. However, these simulations do not match the geological observations that suggest a more complex relationship between glacial lakes and ice margin retreat rates. As such, the fundamental premise of this study to identify potentially counteracting effects of glacial lakes that may stabilise retreat patterns is important. The authors’ results do provide some evidence of this complex relationship between lakes and ice margin retreat dynamics.

My background is in glacial geomorphology with a focus on the North American Ice Sheet Complex and glacial lakes. As such, I cannot comment on the finer details of the modelling set-up, but the approach seems appropriate for a first attempt at quantifying this effect. In general, the manuscript feels well written and the figure choice is appropriate. However, I do feel that the manuscript is a little short and some sections of the supplement should be included in the main text and there is definitely scope to expand the discussion. The conclusions seem slightly overstated but generally appropriate. There is a wealth of geological data on the retreat of these Northern Hemisphere ice sheets and it felt like a little bit of a missed opportunity that there is no attempt to make a comparison to any of this data. If the authors would prefer to keep this study as a purely numerical modelling sensitivity study, then I would suggest reframing it as such in the abstract and conclusions (e.g., ‘proglacial lakes can substantially modulate...’ rather than definitively stating they do, or simply ‘the influence of proglacial lakes on ice sheet surface mass balance’) and highlighting this as foundational work for future model-data integration.

Overall, I believe the authors have done a good job at trying to tackle a problem that has received a little less attention recently (compared to the lake instability ideas). I enjoyed reading the manuscript and I believe their results could form the basis of some interesting work in the future. But, I do have a list of comments and corrections that I highlight below that I believe could improve the manuscript. My comments are separated into broader, general comments first and line-by-line comments second.

### **General comments:**

- Time period choice – In the abstract you state that the time period choice for this experiment is ‘inspired by the Allerød interstadial’ but nowhere in the text do you give a full justification for the time period chosen. Is your time period choice intended to suggest that the formation of large proglacial lakes at the end of the Allerød interstadial could have caused dramatic cooling and ice margin stabilisation during the Younger Dryas? I don’t think there is necessarily anything wrong with the time period chosen, I would just like a more clear framing of why this time period was chosen and a bit of caution about the insights that can be taken from this time period.
- The time period choice is also interesting because you set up your model and evaluate the influence of these lakes, but there is a considerable lake history prior to 13ka. I wonder what role

considering this longer lake history would have? Suggesting lakes as a stabilising influence due to the dramatic influence they hold over climatic conditions is maybe complicated by the fact that lakes tend to grow slowly following ice sheet retreat. Is there a threshold you believe that would tip lakes over into being a stabilising influence?

- You state throughout that this modulates ice sheet retreat, but the approach taken doesn't directly demonstrate this since the ice sheet geometry is fixed and you aren't actually modelling dynamic retreat. I would suggest stating this more cautiously as a potential modulating influence that should be tested in coupled ice-climate models. This would frame your work better as a potential first step towards this goal, which I feel is more appropriate.
- Following up from that, I feel like you could be a little more confident in your conclusions if you attempted to make some comparisons to geological records to potentially highlight these results. Without any attempt to make this comparison it feels like the study should be phrased a little more conservatively as a kind of model sensitivity analysis.
- As a follow on, is there any comparison of the LakeCC outputs you have generated and geologically reconstructed lake extents? Are your lakes realistic?
- Why are ocean surface conditions and a land sea mask taken from a 15ka simulation? Some of the model setup feels quite brief and could be expanded upon.
- How much does lake size matter. In North America (even in your simulation), you also have a second large glacial lake (glacial Lake McConnell). What is the influence of these smaller lakes?
- How could model resolution affect your results? In your simulations Agassiz is just 11 pixels, would a higher resolution model have much of an impact? In general, it feels like there are no other sensitivity tests for other parameters that might influence the results? But, again, my direct experience of modelling is limited so I would leave this to another reviewer to hopefully comment on the appropriateness of this set up. It currently just feels like the uncertainties are not super well constrained and I do believe the results are valuable, but that this could be framed more as a first step.
- On all figures, the choice of line colour to delineate lakes and ice could be slightly higher contrast, currently I find it difficult to distinguish. Perhaps using a black outline for ice and a blue outline for lakes could be a better contrast.
- The naming scheme of the simulations – currently you describe your reference simulation, the warm lake simulation and then the cold lake simulation. Whenever I was reading the manuscript I kept reading PL13ka and expecting it to be the warm simulation, just because that one was introduced first. Could we possibly rename PL13ka to PL13ka<sub>cold</sub>. I think it would just be clearer to always state whether the lake simulations are warm or cold.
- I would appreciate a greater description and comparison of the differences in lake influence between the two areas. It looks like the influence of Agassiz is greater across North America, than for the Fennoscandinavian lake. Is this true? Why? Any other comparisons of the effects would also be interesting. What are the reasons for the changing precipitation patterns between different simulations?
- I am not a palaeoclimate modeller but a 250 year model spin seems a little short, is there a reason for this? Or I might just be wrong and this length is appropriate!

### Line-by-line comments:

Abstract – The opening line is a little confusing, you state that proglacial lakes existed and that they were cold... But why? I don't get a sense of the importance of the study or why the lakes being cold matters. Please be explicit that large lakes developed, they were cold and that this may have influenced climate and stabilised ice sheet retreat. It might also be worth highlighting in the abstract that previously people have suggested lakes are a destabilising influence and that you are attempting to assess the opposite. You bring this in at the end, but I feel like you could have this element earlier to stress the importance of your work.

Line 19 – The Austermann reference is more complicated than highlighting just dynamic retreat. This approach looking at geological evidence (Figure 4) shows a complicated relationship with lakes sometimes driving fast ice margin retreat and sometimes not seeming to have much of an influence. This is a good justification for your study and I think you could make more of some of these kinds of observations. I think you could actually use the output from this study, look at the changing lake area during deglaciation and compare it to changes in ice sheet extent based on ice margin reconstructions (e.g. the Dalton reconstructions) and see whether there is a point where large lakes relate to slower ice margin retreat as a way to support your model observations.

Line 50 – When you talk about the Allerød interstadial, especially in the first mention, you should describe what it is, including defining the full time period of the interstadial (13.9-12.9ka). This is important context for readers to highlight that you are focusing on the end of a warm period.

Line 51 – Should it not be 'atmospheric general circulation model'.

Line 54 – '... allows us to investigate...'

Line 64 – Why are ocean conditions from 15ka used for a 13ka simulation?

Line 85 – 'appear to be sufficiently equilibrated' How did you assess this? Was this qualitative or do you have some quantification that you can use to demonstrate this?

Line 90 – 'A model intercomparison demonstrated...' switch to active voice

Line 160 – '~~We would like to note that~~ surface melt...'

Line 201 – Define Saalian. When is the Saalian and what is the Saalian?

Line 216 – The Austermann et al. (2022) paper would also support this point about non-uniform retreat patterns (see their Figure 4).

A quick follow-up, I think your study and results do show something interesting and important, but here I think you have an opportunity to expand and attempt to validate your results by making comparisons to some geological data. Can you attempt to relate geological observations of ice margin retreat rates with changes in glacial lake extent? For example, use the Dalton et al. (2020) ice margin chronology to calculate the changes in areal extent of the Laurentide Ice Sheet through time. Calculate the lake extent change through time from Austermann et al. (2022). Compare these changes to test whether periods of large lake extent correlate with slower retreat rates?

I have a general belief that model simulations without verification against geological constraints are of limited use, so this would provide independent validation of your modelled effects and strengthen your conclusions about lakes as a stabilizing influence.

You are welcome to say no to this but I don't feel like these plots would take that much time and might provide a geological comparison to back up and strengthen your conclusion.

Figure comments – would it be possible to get a scale bar and lat/long grids for each figure?