

Review of “Four North American glaciers advanced past their modern positions thousands of years apart in the Holocene”

Letter

Dear Editor,

I greatly appreciate the opportunity to review this paper. I also thank the authors for preparing this manuscript.

The research in this manuscript examines the retreat histories of four glaciers in western North America since the start of the Holocene using ^{10}Be and ^{14}C and a model of possible retreat and erosion scenerios that could result in these measured values. The results show that the glaciers experience different retreat histories, despite the expectation that they experienced similar climate forcings. Furthermore, the role of hypsometry and glacier response time drive some of the variability between the four glaciers.

I enjoyed reading this manuscript and believe that it could be a contribution to the literature. However, there are several large issues that that I believe need to be resolved or clarified before publication. Some additional interpretation of the data is needed. Additionally, at times, the writing needs improvement, reorganization and clarification. Comments related to the presentation are presented below, however, the list is not extensive.

The matters presented below can largely be addressed, in my opinion. In turn, *major revisions* seem appropriate. My comments are in normal font and quotes from the text are in italics.

I wish the authors the best in developing this work and hope that this review is helpful to that end.

General comments

- The authors seem to suggest that variable glacier response times and their current position, as opposed to climate variations, drive the different exposure-advance histories in front of the glaciers. Do more local climate records exist for each glacier that could replace or supplement Figure 7 to verify that the climate was indeed consistent in these areas? This statement should better supported: *Although it is possible to interpret the range of bedrock burial durations as bellwethers of previously unrecognized climate heterogeneity over the Holocene.* For instance in lines 300 to 305, glacier extent and climate is determined from lake sediments for the Sierras, then more global sites are mentioned. Surely there are climate differences across some spatial scales. In the most basic case, better describing the consistent climate will make the paper more accessible to those without a paleoclimate background.
- Some what related to the last point, the study site at Coness Glacier needs special attention. This is a very small glacier and it is likely that ice flow is minimal. As a result, factors such as slope, mass balance gradient, and glacier response time might have limited meaning here. Mauro Fischer and Matthias Huss have several papers on the differences in behavior of small glaciers in a changing climate compared to larger ones. The authors should integrate some of thier work (or similar) into the findings here. I find this especially important given that Coness glacier is an end member in the findings presented here.
- smaller/similar note: is JIF glacier connected to the Juneau Icefield? this will surely impact its response time.
- Some matters in the model need clarification and reanalysis. First, I did not find a convergence test or criterion to show that the number of model runs was adequate to yield a robust result.

It *seems* that erosion occurs only when the rock is covered by ice, which is good, but I am not certain that this is what was done from reading the text.

Furthermore, in my interpretation of the text, erosion rates do not vary through the model run, but are held constant through the model run. There has been much research in recent years to show the substantial temporal and spatial variability in glacier erosion, subglacial sediment accumulation and sediment export (Herman et al., 2015, Lai and Anders, 2021, Seguinot and Delaney 2021, Delaney and Anderson 2022, Stevens et al, 2022, amongst others). In the most basic sense, abrasion predominantly comes from sliding, which itself largely depends on ice thickness, which changes substantially through the study period. As a result, I find that keeping the erosion rate constant through the model run is inappropriate. While the number of needed model runs will substantially increase, I believe that variability in erosion needs to be addressed, especially given the findings presented later. This process would be especially important at Kokanee glacier, where advances and retreats could have occurred.

Also the range of possible erosion rates should be increased past 0.5 mm a-1. This is smaller than the erosion rate of many glacierized catchments, much less below a glacier. This is especially true given the evident impact of erosion the results of JIF glacier, and the potential of erosion to impact the histories of other glaciers.

- Consistency and organization in writing. Writing style is largely a matter for the editor and the authors. However, there are many instances where I found the writing need improvement in consistency, precision and organization. Use of the word “how”, for instance, in parts of the abstract and introduction, I found lead to unspecific and vague analysis. I recommend changing throughout. Some specific issues are addressed below. Note that despite these issues, I found several parts well written, and I am confident that with some help and time these matters can be resolved well.

Specific comments

- **Ln 20.** Seems like a word is missing and aren't all glaciers either larger or smaller than in the past?
- **Ln 29.** *the ... variable? spatially changing? ... intensity and rate of modern warming.*
- **Ln 34.** *glacier change.* volume change, velocity change, length change, slow done? can be more precise.
- **Ln 40.** *How glaciers...* seems unconnected to this paragraph
- **Ln 42.** what is an *extended ice position*?
- **Ln 49–55** some citations are needed. I also recommend considering Anderson (Geology, 2014) and Rowan (ESPL, 2022) to better interpret the moraine records.
- **Ln 58** *how their length incorporates climate* this is quite vague.
- **Ln 62** *industrial change...* in climate? precipitation? pollution?
- **Ln 89–107** much of this is background knowledge (or even results (should a citation not be present)), as opposed to “Glacier setting...’
- **Ln 108** Is JIF glacier connected to the Juneau Icefield? if so this could have some pretty big implications for the response time compared to Coness for instance.
- **Ln 110** Surface slope is brought up here and in other locations through the manuscript. However, given the retreat and advance variability found later, these slopes will have surly changed through the Holocene. Would this impact your analysis?
- **Figure 2** the vertical axis is strange in that it is a percent of area (m²) to extent (I think of as length (m)), so I am not quite sure what it represents or if units are correct. Clarify.
- **Table 1** *trimline and moraines...* This is not my expertise however, I am aware of much debate about the meaning of trimlines, and previous work about moraine records have been mentioned above. Please consider if relevant.

- **Section 3** This section appears to be more about “Methods” as opposed to “Materials”
- **Ln 183** *We assume all samples experienced the same...* all glaciers from the same glacier? please be more precise.
- **Ln 189–196** some of this might be considered a result or source of uncertainty that should be discussed later, in my opinion.
- **Ln 199–200** This sentence might need to be more precise, I am not sure it establishes the precise role of the model.
- **Ln 213–214** *100,000 scenerios is tested 26 times.* I do not understand this.
- **Ln 214–215** *2- σ uncertainty...* of what? the concentration? also is the 4% error in the measurements accounted for in the inversion? if not then it seems that the 2 - *sigma* uncertainty is too precise.
- **Figure 4** I like this Figure quite a bit! However, the points outside the envelope are quite interesting to me. Can this analysis be moved up in the results?
- **Figure 5** Sample locations for Kokanee glacier and Mammoth glacier seem to suggest that that the samples we not exposed at the same time. Please comment on this. Such variability might impact the exposure-burial histories in Fig 6.
- **Ln 283** What is the criterion for a sucessfully reproducing the erosion rates?
- **Ln 284** Given that the mean erosion landscapes is on the order of 1-2mm a⁻¹ (Hallet et al., 1996), I am not sure that .5 mm a⁻¹ is especially high.
- **Figure 6** Since the model is run in with MC, a range of model runs or confidence intervals can be shown on this plot. This would greatly increase the confidence of the results.
- **Ln 295** *all four glaciers ... glacier expansion* How it is known from your data that Conness glacier expanded as it was covered the whole time?
- **Ln 296** *early to late Holocene* isn't this the whole of the Holocene?
- **Ln 300–304** Without knowing the specific papers regarding sediment flux into lakes, it has been well documented in recent research that glacier retreat, as opposed to advance, can lead to increased sediment discharge from glacierized catchments. Thus, please reconsider the robustness of this analysis.
- **Ln 303–305** These regions are far apart with different climate forcings. To make this statement more than correlation, analysis of the global climate is needed. This should be commented upon.
- **Figure 7** Please explain the meaning in the hydroclimate index. What is wetter, for instance?
- **Ln 349–357** To me, this paragraph seems highly speculative, especially as the model does not recreate the rations. Why is it then the preferred explanation? I would be hopeful that more modeling work would be useful in sorting this out.
- **Ln 365** *JIF Glacier is uniquely erosive amongst the four glaciers studied here.* I am not sure how this can be varified. While JIF glacier does plot outside of the envelop in Fig 4, the role of erosion could also impact the histories of the other glaciers, yet the impact could be less suspect because they plot within reasonable values.
- **Ln 375–377** *interspersed episodes of glacier retreat...retreats were of minimal size if they occurred at all.* These sentences seem contradictory. Why would retreats not occur at all, given Fig6. Also, I was tempted to draw another conclusion from this paragraph until I referred to Fig 6. Please reference a figure in this paragraph to support your findings.
- **Ln 378–390** This could be considered results.
- **Ln 389** What simplifications were made in the isochron plot?

- **Ln 391** *Mammoth Glacier is 50%... doubled in size...* I do not follow, maybe it is a problem with the tense.
- **Ln 394** *ice dynamics plays a role...* doesn't ice dynamics always play a role?
- **Ln 398** I think this sentence needs to be more precise.
- **Ln 414** What about subglacial sediment deposition and insulation from erosion? (Beaud et al 2018, Delaney and Anderson 2022, Stevens et al. 2022).
- **Ln 419** *buried*. By ice or by debris?
- **Ln 440–450** I think there is some valuable information in this paragraph. However, much of it is quite general and difficult to link to the paper's findings. Some time distilling this is needed.
- **Ln 449** *their modern positions are more variable than in the past*. I am not sure how this conclusion was arrived at.
- **Ln 459** Please describe a *quicker glacier*.
- **Paragraph 462–475** What is the input data for the glacier response time?
- **Ln 493** *that modern retreat is a reversal of a long-term trend of glacier advance in western North America...* where do the data presented in this paper show that the glaciers have advanced, as opposed to simply covered these bedrock areas? is "modern" considered since the LIA?