Reviewer Comment 2:

Alia Lesnek

In this manuscript, Hawkins et al. present a new ^{10}Be chronology of late Holocene moraines in northwest Canada. They also reconstruct past regional climate from modeled glacier ELAs, simulate glacier volume over the past millennium, and forecast future glacier volume over the next century. The topic of this manuscript is well-suited for publication in *The Cryosphere*. In all, there's an impressive amount of work that went into this study. The results and interpretations will be a useful contribution to our knowledge of past and future glacier change in Canada.

That said, the manuscript would benefit from revision before publication. Below, I've provided a few 'major' suggestions for the authors to consider; these are not all that major in the grand scheme of things, but may require substantial revisions to the text and some figures. I've also included a number of minor suggestions, indicated on a line-by-line basis. I hope that my comments offer constructive ways to improve the manuscript.

Thank you for taking the time to review our manuscript and for your helpful comments and insights. We have discussed and addressed your comments below and incorporate many of your suggestions into our revised manuscript. Please see our responses in bold below.

Major comments

Interpretation of ^{10}Be ages*:* The pre-LIA exposure ages in your chronology are under-discussed in my opinion. I recognize that the number of exposure ages that you have per moraine is somewhat small and you are probably wary of over-interpreting your data, but if you assume that the late Holocene moraines date to the same event (which it seems you do based on your ELA reconstruction and modeling approaches), then I think you can expand your discussion of the exposure ages in at least two major ways.

First, the fact that you have erratics with consistent 11 ka exposure ages just outside of the late Holocene moraines suggests to me that the moraines were emplaced by a glacier readvance rather than a stillstand. Young et al. (2013), *QSR* have a nice discussion about using exposure age distributions to infer that a readvance created some of the Fjord Stade moraines in western Greenland. The distinction between a readvance and a stillstand to create the late Holocene moraines is an important one for your modeling and paleoclimate interpretations, and I think your dataset does allow you to distinguish between these two scenarios.

Thank you for your thoughts and discussion on our erratic boulder ages. An important distinction between the moraines in Young et al. (2013) and the erratic boulders sampled in this study is that our erratic boulders were not a part of any moraine system. Similar erratic boulders were dated by Menounos et al. (2017) that lie beyond cirque moraines and their ages were interpreted to reflect the age of local deglaciation. Since no landform was associated with these erratics (or those in the present study) we can only report

deglaciation rather than whether the cirque glacier was more or less extensive. In addition, Menounos et al. (2017) found that some erratics and end moraines dated to the Younger Dryas termination. The most parsimonious explanation for coeval ages and associated geomorphology was the complex decay of the Cordilleran Ice Sheet (i.e., some cirques were still inundated by the ice sheet whereas others were ice free prior to the Younger Dryas and so could form an end moraine). We now bring up this point in the Discussion section of the manuscript.

Second, given that these glaciers likely readvanced to deposit the late Holocene moraines, it seems reasonable that the boulders with exposure ages between 1-4 ka were reworked and therefore have small, but variable amounts of ^{10}Be inheritance, and that the younger cluster of exposure ages more closely constrains the timing of moraine abandonment in your study area. That said, it's also possible that the younger exposure ages are too young due to snow shielding or exhumation (e.g., although there isn't a lot of debris on the glacier termini now, I could *potentially* see a scenario where the moraines were ice-cored early in their history and the youngest exposure ages are actually reflecting the timing of moraine stabilization in the region). However, to my eye, the tight clustering of young exposure ages across the six glacial systems combined with the scattered "old tail" of ages seems most easily explained by the inheritance interpretation.

As noted by Referee #1, we concur with your assessment here. We now expand on this point in the Discussion section of the paper.

These are just two areas where I think you can beef up your ^{10}Be interpretations. A more thorough discussion of the above ideas (and other relevant ones that you may come up with during the revision process) as they apply to your study area would support the modeling you do later in the paper and strengthen your overall conclusions about glacier history in NW Canada.

ELA estimation methods: In line 407 of the paper and in the conclusion, you recommend that modeling modern glacier ELAs using climate data should be preferred over methods that rely on glacier geometry. I'm not fully versed on all of the latest glacier ELA literature, but this seems like an important outcome/recommendation from this study. Perhaps it's outside the scope of this paper or it's already been done by others, but I wonder how ELAs modeled based on climate data compare to ELAs calculated with *in situ* mass balance measurements. Are there any examples of glacial systems where this has been done before? Or even better, any glaciers in your study area with *in situ* mass balance measurements and corresponding ELAs that you could compare with your modeled ELAs to validate this approach?

Unfortunately, there are few glaciers within our area that have mass balance records for any significant length of time. The Geological Survey of Canada has periodically completed mass balance campaigns on Bologna Glacier at the northern end of Nahanni National Park Reserve. We are unaware of other papers that directly compare ELA's produced by coupled glacier/climate models compared to geomorphic ELA estimations. However, modelled ELAs have been compared with *in situ* ELA measurements (e.g. Braithwaite and Raper, 2015; Keeler et al. 2021). An important limitation to a flowline glacier model, as used in this study, is the glacier bed geometry strongly influences model behavior. In

OGGM, bed surface topography is estimated with a surface inversion model, which may differ significantly from the actual glacier bed geometry. In addition to employing glacier models of greater complexity and high-resolution climate models, utilizing ground penetrating radar surveys to map subglacial topography would improve model performance. Implementing these suggestions are outside the scope of this paper, but may be fruitful avenues for future research.

Modeling details: The modeling exercises you did are a useful contribution, but the description of your model setups, particularly for the transient OGGM experiment, could use more detail. Perhaps I missed these things, but for example, where are you getting the starting values for glacier volume at 1000 CE? Are these coming from moraines or some other source? What ranges of Tbias and Pbias did you use to tune the climate models, and how do these bias values compare to what's known about regional climate over the past 1 kyr? And more generally, why simulate the past millennium rather than some other time interval?

You bring up valid, useful suggestions here. Tbias and Pbias ranges are now added to the Methods section. These biases are adjusted to minimize the difference between the modelled and "observed" glacier extent for each glacier and do not represent "real" climate information and so are not compared to the known regional climate. We chose to spin up the modeling based on our use of the GCM transient runs available to us (Eis et al., 2021; Huss and Hock, 2015). Since these runs commence at 0850 CE, that provides us with 150 years of 'spin up' for the glaciers. We now describe that in more detail within the revised manuscript and will clarify the spin up duration on Figure 5.

Figure 5: It would be helpful to include the known glacial history on this figure so the reader can see how the modeled glacier changes compare to the geologic constraints. I know this figure is showing ice volume for all 1235 glaciers in the study area, but a second panel showing something like a generalized time-distance diagram normalized to glacier length for the glaciers you studied in detail (incorporating data from the moraines and the satellite imagery) would help readers evaluate the results of your modeling.

This is a great suggestion, and Figure 5 has been edited to show this.

Minor comments

Line 117: Can you include a supplemental figure showing your late Holocene glacier margins? Drawing paleoglacier margins can be quite challenging in the accumulation zone where there are no moraines, so this would be helpful to see.

We now include a Supplemental Figure showing the digitized margins of the glaciers used in ELA reconstructions. As noted in the figure caption, not all margins include the accumulation zone, as the primary focus was to measure the distance along the central flowline of the glacier to the where the flowline intersects the glacier terminus at each time step.

Line 145: Are the exposure ages presented in the main text calculated assuming no surface erosion or snow cover?

We added clarification that snow cover and erosion is not corrected for in the presented exposure ages. We do present exposure ages with a reasonable snow cover for the region in SM Table 4. We expect erosion rates to be low and snow cover of minor importance, given the relatively young ages of the moraines.

Line 178: Which glacier extents? Modern and LIA? What year did you use for your "modern" glacier extent (since you seem to have digitized glacier extents for many years from Landsat imagery)?

Clarification added to specify that the "modern" glacier extents are from imagery between 2017 and 2021 CE for each glacier.

Line 235: This choice of mass balance gradient seems reasonable for a modern glacier, but I wonder how much of an impact that choice makes on your model output, especially since your glaciers advanced into the LIA?

This is an important limitation to our method and is now addressed in Discussion. We do not have multi-year mass balance gradient observations from nearby glaciers in this region.

Line 334: This SM table citation doesn't look like it goes to the correct table.

We apologize for this error. The first few SM tables were out of order in the original submission, now corrected.

Line 458: Reading this section and the last line of your conclusions, I'm left wanting a bit more information about the wider implications of glacier loss in this region. What specifically are the potential impacts on ecosystems? Are there people who rely on these glaciers for water, etc.?

Additional information on the cultural and ecological setting of the watersheds in our study area added to the Study Area section. We now note in Discussion that we cannot constrain the impacts to the ecosystem from glacier loss in this region, but we do mention potential impacts to local fisheries that are important to local First Nation communities.

Figure 2: This figure would be improved by adding your exposure ages and/or sample IDs so your readers can see how the ages are distributed across the moraines. Are the erratic boulders also included on this figure? It's hard to tell.

Sample ages are now added to Figure 2 along with inset maps that show greater location detail for individual samples, including erratics.

Figure 3: Can you also show the individual exposure ages on the kernel density plot below the red summed curve? That will be useful for seeing how many ages contribute to a particular peak.

A great suggestion. We now include individual samples to the figure to better show distribution and contribution to peaks.

Figure 4: Define the abbreviations Tlower, Smb, etc. in your caption and in the relevant methods sections. I didn't see these terms defined until the discussion.

Agreed.

Table 1: Exposure ages should be rounded to the nearest decade.

Agreed.