Response to reviewers and commentors, Walcott et al., 2023

We included all reviewer comments as normal text and our responses as *italicized blue characters.* Please note all page and line numbers referred to here are in reference to the *tracked-changes* version of the revised manuscript.

REVIEWER 4

We thank the anonymous reviewer for taking the time to review our manuscript. The comments were quite helpful and strengthened the manuscript.

The paper presents an interesting assessment of Last Glacial Maximum ELAs across Alaska that is of interest to the wider scientific community. I find that the authors have addressed the comments put forward by previous reviewers relating to the approach used to delineate former LGM and LIA limits (including chronological constraints and uncertainties associated with asynchronous advances), the spatial distribution of LIA glaciers used, and implications for / comparisons of palaeoclimate. However, I think a little more could be done in places to fully address these comments that would further enhance the paper. Some additional figures would help to achieve this and I have added specific comments to the attached pdf.

Major Comments

1) The approach used to delineate former LGM and LIA limits – Whilst further details have been added to the text, as requested by Reviewer 3, a figure showing either an example mapped valley with LIA and LGM limits and/or example photographs (or Google Earth images) of LIA and LGM limits would be most helpful. The analysis presented relies on correct identification of LIA and LGM limits and therefore demonstrating that valleys that have not been chronologically constrained can be included based in their geomorphological characteristics is important. There is only a passing comment on identifying LGM glacier limits on page 8, line 21, and some further details are needed.

We added the below text to Section 3.2 to make it unequivocally clear where the LGM limits are coming from, and note that we refined lower-resolution paleoglacier limits, but broadly followed their MIS 2 extents.

"The Alaska PaleoGlacier Atlas v2 provides (Kaufman et al., 2011) shapefiles of glacier extents from different glaciations (i.e., MIS 2, MIS 4, and earlier) that are dated using available chronology, while Balascio et al. (2005a) provide paleoglacier information solely from the LGM…"

"We then undertook more detailed mapping of LGM paleoglaciers based off these previously published extents (more detail was often necessary than that included in the Alaska PaleoGlacier Atlas) using well-established practices including identifying terminal and lateral moraine crests, trimlines, and cirque headwalls, to create higher resolution shapefiles of LGM glacier extents (Fig. 3; e.g., Chandler et al., 2018)."

We added a new figure (now Figure 2), showing an example of Alaska PaleoGlacier Atlas v2 MIS 2 and MIS 4 extents, for comparison with our higher-resolution mapping based off these datasets.

We also added a second new figure (now Figure 3) that shows an example of sharp-crested, clearly delineated Little Ice Age moraines and their unvegetated surfaces.

2) Clarification on the rationale for glaciers selected for LGM and LIA ELA analysis – Are the 480 LGM glaciers all independent valley glaciers or do these include outlet glaciers from ice caps or transection glaciers? The absence of any figures relating to the mapped LIA and LGM limits does not help to clarify the intext discussion here – it would be helpful to see situations where LGM and LIA limits were included in the analysis vs situations where they weren't. The rationale for focussing on independent glaciers only for ΔELA is also unclear and could be strengthened, not least because ice divides from the Randolph Glacier inventory could be used or reconstructed based on present-day watersheds. Since ΔELA is based only on independent valley glaciers, there needs to be a comment/discussion on how ΔELAs of larger ice masses that haven't been included might have affected the results.

Indeed, the 480 LGM glaciers were selected using the criteria that we sought are independent valley glaciers from which we believe reconstructed ELAs are the most robust. We added text (see below) clarifying this LIA glaciers are not ice caps – instead these are also all independent valley glaciers. There were no instances of a valley where the LGM glacier was an independent valley glacier but the LIA glacier was part of an ice cap. Instead, we only found the opposite: independent LIA glaciers in valleys that were once covered by LGM ice caps. I believe, however, that this comment refers to LGM glaciers. While the RGI is certainly useful for reconstructing modern ice caps, we are not entirely sure how this could help with reconstructing LGM ice caps. While we may be able to use this to delineate present-day watersheds, since the thickness of the LGM ice caps are unknown (i.e., once the ice caps are above mountain peaks, it can be hard to constrain their heights), this would likely influence LGM watersheds and thus, ice flow, surface area, and ELAs. Furthermore, while GlaRe can reconstruct the ice surface of small ice fields (~200 km^2), it has not yet been tested for large and complex ice caps (i.e., Brooks Range and Ahklun Mountains), and as we encountered some computational issues with our large valley glaciers, it is also likely computationally unfeasible. Ultimately, we believe that by sticking with independent mountain glaciers, both during the LIA and the LGM, our ELA reconstructions are most robust. Finally, we do not believe that adding in ice cap systems, even if we thought ELAs from them were reliable, would lead to a regional ELA being higher or lower.

Text added:

Section 2:
"We reconstruct paleoglacier surfaces for 480 independent LGM valley paleoglaciers, and do not include ice caps or large ice fields, such as the those that covered the Ahklun Mountains and the Brooks Range."

Section 3.2:

"We focused on independent valley glaciers for their simple geometry and relatively simple relationship between their size and climate (e.g., Oerlemans, 2005). We exclude ice caps and ice fields, such as those that covered the Brooks Range and the Ahklun Mountains, as GlaRe is not suited for such large and complex features, especially given inconsistent moraine preservation and a dearth of evidence on ice cap extent in some areas of the Brooks Range and Ahklun Mountains (Kaufman et al., 2011). Additionally, a lack of published data on paleo ice divides, ice thicknesses, and bed topography for these ice caps, hinders our ability to accurately reconstruct their surfaces, and thus their ELAs."

Section 5.1:
"Though we did not calculate ELAs for the ice caps and ice fields over the Brooks Range and the Ahklun Mountains, it is unlikely that their ELAs would vary much from the surrounding independent valley glaciers. As the ELA of glaciers, including ice caps, are largely controlled by summer temperatures and annual precipitation, it holds that ice masses from similar locations should have similar ELAs. The ELA of large ice caps can vary across large geographic areas (e.g., Burgess and Sharp, 2004). Thus, we would expect the ELA of the Brooks Range ice cap, which stretched for ~1000 km from west to east to vary similarly to the ELAs of independent valley glaciers on the western and eastern edges of the range, and not significantly influence our findings."

3) Discussion Section 5.1 - It needs to be made clear in the text whether you are discussing present day to LGM ΔELA or LIA to LGM ΔELA.

Thank you for pointing this out. We will add text to clarify this at every occurrence.

Specific Comments

Page 4, Line 21 – "how many?"

we added the number of glaciers reconstructed

Page 4, Line 23 – “reference?”

we added the reference for the Alaska PaleoGlacier Atlas v2 earlier

Page 4, Line 5 – “explain how this is calculated”

we added “(LIA_ELA – LGM_ELA)”

Page 6, Line 7 – “See also Carrivick et al. 2023 GRL Greenland.”

Thanks for passing along this neat paper! Unfortunately, we are referencing manuscripts that compare LGM ELAs to ELAs from other time periods. It looks like Carrivick et al. apply this technique to post-LIA change. A very great application of ELAs, nonetheless, but not relevant to our point here.

Page 6, Line 23 – “Use commas rather than dashes”

We choose to keep dashes here, as a stylistic choice.

Page 8, Line 4 – “LIA-LGM? or modern-LGM?”

We added “(contemporary ELA – LGM ELA; see below)” to highlight where we discuss this point.

Page 8, Line 18 – “Be clear what this change is referring to”

We added another instance of LGM to be clear. We haven’t yet discussed the Little Ice Age in the manuscript up to this point, but we clarify this point in the following paragraph. Adding this here earlier would be out of context, we feel.

Page 8, Line 21 – “explain what these are here”

We believe that these discussions of the evidence for glaciation should be kept to the methods section, rather than devoting a good portion of the introduction to this.

Page 9, Line 17-18 – “Can you be clearer what you mean here or show some example figures? - surely if it was an outlet glacier of an ice cap you could still calculate an ELA?”

We addressed these comments as outlined above.

Page 11, Line 5 – “So used more than just a central glacier flowline?”

Yes – we added “multiple” to clarify this

Page 11, Line 12 – “Cna you explain why you didn't include ice cap outlet glaciers? Could have used current watersheds or the Randolph Glacier inventory for the ice-divides.”

We addressed this comment above.

Page 11, Line 14 – “A photo would be helpful to show this”

We added Figure 4, which shows this!

Page 12, Line 5 – “for mid-latitude, clean ice glaciers?”

Oien et al. (2021) found in their comprehensive study that an AAR of 0.58 should be applied to ELA calculations for all latitudes

Page 12, Lines 10 – 13 – “Can you expand a little to explain why you used this rather than a more regional BR (e,g. Rea, 2009)” and “Need to explain a little more where these error estimates are derived from.”

We edited the text in Section 3.3: “We employ a ratio of 1.56, which a recent study has found to best represent glaciers worldwide, where there are no better available regional AABR values – this is true for Alaska both today, and during the LGM and LIA where the balance gradients are unknown (Oien et al., 2021). We calculated ELAs using LGM and LIA glacier surfaces as inputs to an ELA calculation toolbox in ArcMap (Pellitero et al., 2015). We applied standard, previously published errors of 65.5 and 66.5 m for our AABR- and AAR-calculated ELAs, respectively, as provided by Oien et al. (2021).”

Page 13, Line 11 – “Rephrase the sentence to make the point clearer, e.g. "We consider our calculated temperature depressions as maximum depressions because...."”

We changed, per the reviewer’s suggestion

Page 13, Line 17

Thanks for catching our typos – we considered the comments and streamlined the passage below:

“LGM lapse rates are unlikely to have been lower than modern lapse rates because drier air produces smaller magnitude lapse rates because the lapse rate of an air mass increases as it loses its moisture through condensation.”

Page 15, Line 21 – “Explicitly state what the change in ELA is here, i.e. LIA to LGM”

We have changed all instances of this.

Page 23, Line 11 – “Do you mean LIA to LGM depression? or are you saying that LGM was warmer? It's not clear”

We changed to “and others showing small LIA-LGM summer temperature depressions of -1 to -4 °C”

Page 24, Line 17 – “Use brackets”

We feel this is a stylistic choice and choose to keep the em dash.

Page 24, Line 18 – “repetition”

We changed one instance to “highlight”

Page 25, Line 18 – “define time period”

We added this.

Page 26, Line 12 – “Not good practice to start a sentence with 'because' let alone a paragraph. Switch the sentence structure around to avoid this.”

Again, we believe this is a matter of stylistic choice and thus did not edit this.