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

Submitted by Caleb Walcott on behalf of the author team.

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 1

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

Major Comments

1. More information/justification is needed on the LGM and LIA datasets used for this study.

-LGM glaciers: In Section 3.1 you state that "…we used the Alaska PaleoGlacier Atlas v2 to guide our mapping of LGM ice extents." Were LGM glaciers mapped that are not in the Atlas? If so, information should be presented to document how that was done. If not, be clear in the text that 'all' individual LGM glaciers mapped are from the Alaska PaleoGlacier Atlas v2.

We are happy to provide more information. Indeed, a few LGM glaciers not in the Alaska PaleoGlacier Atlas v2 were reconstructed, primarily in the Brooks Range. Here, we were guided by the previous mapping of Balascio et al., 2005. Additionally, for the majority of our study glaciers, which are included in the Atlas, we needed to increase the resolution of the polygon, and thus added detail guided by the Arctic DEM shaded relief map. Please see the updated text below from section 3.2, page 10, line 19 to page 11, line 3.

"We used shapefiles of LGM paleoglaciers from the Alaska PaleoGlacier Atlas v2 and glacier center coordinates from Balascio et al. (2005a) in the Brooks Range to roughly identify the extent of paleoglaciers (Kaufman et al., 2011). We then undertook detailed mapping of LGM paleoglaciers (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 more high-resolution shapefiles of LGM glacier extents (e.g., Chandler et al., 2018)"

-LIA glaciers: (i) It is not clear at all how LIA glacier systems were chosen for mapping. Are any of these glaciers systems/moraines chosen based on previous mapping by the authors, or other published information that should be cited (e.g. Sikorski et al., 2009)? (ii) Overall, the LIA data are quite insufficient outside of the Alaska Range. It seems a bit of an overstatement to say that you have calculated ‘state-wide’ LGM-LIA ΔELAs when 90% of the data are from the Alaska Range. Only two of the LIA glacier systems are located outside of the Alaska Range….is this due to a lack of identifiable LIA moraines at other locations in the Brooks Range or the other massifs (which seems hard to believe). Is it possible to include more LIA glacier extents? At least, more information should be provided on the LIA data used, and possibly to temper statements about state-wide trends (or provide more reference to previous work before making interpretations about state-wide trends).

(i). We are happy to provide more information. We have updated sections 2 and 3.2 to reflect this. We now write:

2. Page 9, lines 9 – 28

“During the LIA (dated to the 19th century in Alaska; Barclay et al., 2009), Alaskan glaciers deposited well-defined moraine systems downvalley of extant glacier systems that remain relatively unvegetated and sharp crested (Evison et al., 1996; Kathan, 2006; Molnia et al., 2008; Sikorski et al., 2009; Reinthaler and Paul, 2023). Thus, we can calculate ∆ELAs (ELA_LIA – ELA_LGM) in valleys where simple LGM glaciers were independent from large ice caps or ice sheets, and within which there is also clear geomorphic evidence of LIA glaciers. This precludes us from reconstructing ∆ELAs, however, in valleys with LGM glaciers but lacking LIA glaciers, or where there is evidence of LIA advances, but the valley was covered by an ice cap or ice sheet during the LGM (i.e., much of the central Brooks Range and Ahklun Mountains). Following these criteria results in few ∆ELA calculations outside of the Alaska Range.”

3.2. Page 11, lines 10 – 21

“We repeated these steps for valleys with well-defined LIA glacier outlines where we reconstructed independent LGM glaciers (i.e., not connected to ice caps in the Ahklun Mountains and Brooks Range) to allow for valley-scale LGM-to-LIA comparisons. Little Ice Age moraines in Alaska are defined by sharp, well-defined, vegetation-free crests (Molnia et al., 2008; Sikorski et al., 2009). In these locations, we used LANDSAT8 false color imagery to guide LIA moraine mapping by creating vegetation cover maps, which we used in tandem with our DEM data to identify LIA moraine crests (Chandler et al., 2018; Reinthaler and Paul 2023). Based on Levy et al. (2004) and Sikorski et al. (2009), and our experience mapping former glaciers in Alaska, we have confidence in identifying the LIA moraine. In rare locations, pre-LIA moraines (Late Holocene moraines) may appear as fresh as an LIA moraine, but in these cases the pre-LIA moraine crest is nested adjacent to LIA crests and would not result in a significantly different ELA if mistakenly outlined.”

(ii) This is a good point. We now emphasize that the part of the study area where we have a fairly robust ∆ELA understanding is the Alaska Range, and that we turn to a couple of additional cases to see if this delta value is similar elsewhere in Alaska.

Of course, there are well-defined LIA glacier extents from elsewhere in the state, notably the central Brooks Range, and Ahklun and Kenai mountains. However, our study focuses only reconstructing LIA glaciers in valley systems where we could also reconstruct individual LGM glaciers to calculate valley-specific ELAs, rather than comparing LGM ELAs to the ELA from LIA glaciers from other parts of the range (e.g., Briner and Kaufman, 2000, Balascio et al., 2005a). Nevertheless, we added text in section 5.1 [page 18, lines 4 – 10 and page 18, line 15 – 22] to include some of these studies (other than the Kenai Mountains that fall outside of our study area) and to provide some range-averaged ∆ELAs:

"Our LIA ELAs are comparable to the limited published ELA data from Alaska. In several instances, others calculated LIA ELAs from valleys that were smothered by ice caps or ice sheets during the LGM, and thus we cannot make direct spatial (i.e., valley to valley) comparisons with our data (e.g., Daigle and Kaufman, 2009; Levy et al., 2004; Sikorski et al., 2009; Wiles et al., 1995). However, a study of LIA ELAs in the northeastern Brooks Range reported an average of 1977 ± 102 m asl (calculated with AAR of 0.58), within error of our average LIA ELA from the same sub-range of 1857 ± 47 m asl (Sikorski et al., 2009)…

Additionally, previously published LIA ELA reconstructions using similar AAR values from the Ahklun Mountains and central Brooks Range allow us to estimate range/sub-range average ∆ELAs when combined with our range/sub-range average LGM ELAs (Levy et al., 2004; Sikorski et al., 2009). These yield average ∆ELAs of -372 ± 117 m for the Ahklun Mountains and -249 ± 157 m for the central Brooks Range (errors from average LGM and LIA ELAs are summed). We note that these data do not reflect valley-scale changes in ELA, but rather range-wide shifts. Thus, we do not calculate temperature depressions from these, but provide them for ∆ELA comparison purposes."

2. Background.

The authors do a nice job of summarizing previous work on ELA reconstruction methods and how they have been applied in the past to LGM glaciers in Alaska. However there is no information on the LIA in Alaska. Since the LIA is used as a benchmark for calculating DELAs, there should be some introduction to the LIA in Alaska, including previous work mapping LIA glacier extents, how they compare to the extent of modern glaciers, the timing of the LIA, etc.

Please see our response to the previous comments – we attempted to adequately address these issues there.

Specific Comments:

Page 6, line 1: Not clear how your data will be able to say anything about aridity.

Our data themselves do not say anything about aridity, but this is merely an acknowledgement that aridity has long been used to explain the limited ice extents in Alaska during the LGM. We are stating that our hypothesis of limited temperature lowering does not negate the possibility of this aridity influence.

Page 7, line 10: extra "." before citations

Thank you.

Page 8, line 8: Sentence beginning with "These glaciers deposited…." You should provide references to work that has documented/characterized LIA advances in at least some of these regions in Alaska

Thank you for this suggestion. We added text and citations that both documented and characterized LIA advances in Alaska.

Page 14, line 16: The parenthetical statements in the middle of the sentence starting with "In the Alaska Range.." make it difficult to understand the information presented. Consider moving to the end of the sentence or presenting in a different way. Same for how the first sentence of the following paragraph is structured.

We corrected these sentences.

Page 14, line 22: "We see no statistical relationship between longitude and ∆ELA." I don't think you have enough data from outside of the Alaska Range to suggest that this is significant. If you had better spatial coverage of LIA glacier extents, this would be more of an interesting result.

We added the qualifier "though this may only be reflective of the Alaska Range due to a lack of data elsewhere in the state." Regardless of the lack of spatial coverage, however, our data do not demonstrate a statistically significant relationship between longitude and ∆ELA. Thus, we still report this.

Page 17, line 14: Sentence starting with "Coversely, in Alaska…" needs a reference. What is the justification that Alaska was drier during the LGM, provide reference.

We provided citations for records of aridity in Alaska previously in section 4.4. We do not believe that we need to cite again.

Page 20, line 19: Use “low” or “small” not both, for describing summer temperature depression

Thank you for catching this editing error.

Page 21, line 18: “Our range DELA-derived…” insert ‘of’

Thank you for catching this editing error.

Figure 3: A title is not needed since this information is in the caption. Also, the text is too small in the inset with labels for “LGM” and “LIA” points. The x-axis units are also not intuitive and do not make for easy comparison to locations of sites in the other figures… would be easier to understand if they were in degrees longitude.

Thank you for your suggestion. We have increased the font size of the inset and edited the x-axis to degrees longitude.

REVIEWER 2

This study presents an updated assessment of equilibrium line altitudes (ELAs) for Last Glacial Maximum (LGM) and Little Ice Age (LIA) glaciers in Alaska. ELAs are calculated for the LGM and LIA glaciers and are then used to regional ELA trends across Alaska. Additionally, the ELA data are used to quantify differences in ELAs (ΔELAs) between the LGM and LIA, as well as to estimate the temperature differences between the LGM and LIA. Although there have been several previous studies focused on ELAs in Alaska, this study provides a comprehensive, regional assessment using up-to-date methods. An important aspect is the use of the LIA (rather than modern glaciers) as a baseline for LGM ΔELA calculations. Overall, this study will be of interest to the readership of *Climate of the Past*.

Although this paper has merits and would be of interest to the CP readership, there are some issues that need to be addressed. I have four main comments on the manuscript.

1. Approach used to delineate the former glacier limits: based on the manuscript, it is unclear how the authors mapped and established the LGM and LIA glacier limits. For the LGM glaciers, the authors mention that the 'Alaska PaleoGlacier Atlas v2' was used to guide the mapping of the glacier limits (p. 10), but it is unclear if the authors undertook any original geomorphological mapping. It is also unclear how the limits of the "well-defined LIA glaciers" (p. 11) were identified. There need to be more detailed and transparent explanations of the mapping methods, with reference to established mapping practices (e.g. Chandler et al., 2018).

See our replies above that relate to this comment. We have updated sections 3.2 (page 10, line 19 – page 11 line 21), to better explain our mapping methods and the practices we used.

"We used shapefiles of LGM paleoglaciers from the Alaska PaleoGlacier Atlas v2 and glacier center coordinates from Balascio et al. (2005a) in the Brooks Range to roughly identify the extent of paleoglaciers (Kaufman et al., 2011). We then undertook detailed mapping of LGM paleoglaciers (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 more high-resolution shapefiles of LGM glacier extents (e.g., Chandler et al., 2018). For large valley glaciers, we used watershed analyses in ArcMap to determine glacier flowlines; for small cirque glaciers, we drew lines from the moraine directly to cirque headwall for simplicity. We calculated ice thickness every 25 m along these flowlines using GlaRe and a standard basal shear stress value of 100 kPa across all flow lines to ensure uniformity (Benn and Hulton, 2010; Pellitero

et al., 2016). Using GlaRe, we reconstructed LGM glacier surfaces, using our 'ice-corrected' bed DEMs where appropriate, paleoglacier extent, and flowline ice thickness data as inputs.

We repeated these steps for valleys with well-defined LIA glaciers outlines where we reconstructed independent (i.e., not connected to ice caps in the Ahkun Mountains and Brooks Range) LGM glaciers to allow for valley-scale LGM to LIA comparisons. Little Ice Age moraines in Alaska are defined by sharp, well-defined, vegetation-free crests (Molnia et al., 2008; Sikorski et al., 2009) In these locations, we used LANDSAT8 false color imagery to guide LIA moraine mapping by creating vegetation cover maps, which we used in tandem with our DEM data to identify LIA moraine crests (Chandler et al., 2018; Reinthaler and Paul 2023). Based on Levy et al. (2004) and Sikorski et al. (2009), and our experience mapping former glaciers in Alaska, we have confidence in identifying the LIA moraine. In rare locations, pre-LIA moraines (Late Holocene moraines) may appear as fresh as an LIA moraine, but in these cases the pre-LIA moraine crest is nested adjacent to LIA crests and would not result in a significantly different ELA if mistakenly outlined."

2. Chronological constraints on the glacier limits: linked to the mapping of the glacier limits, it is unclear how the age of the glacial landforms/limits were determined, as there is no reference to any chronological evidence/constraints. The authors need to provide details on how the ages of the limits were established. Are the ages based on 'absolute' chronological data, or are they based on relative methods and/or changes in the glacial landform/landsystem signature? Or is it simply assumed that the limits are either 'LGM' or 'LIA' glacier limits based on their geographical position?

Thank you for your suggestions. We added text on the LGM/LIA glacier limits and ages in section 2. We also included a figure in the supplement (Supplement Figure 2) summarizing available cosmogenic nuclide chronologies of LGM moraines in Alaska.

LGM (page 8, line 19 – page 9, line 5)

"To delineate the extent of LGM glaciers, we rely on decades of field mapping and chronology summarized in the Alaska PaleoGlacier Atlas (Kaufman et al., 2011). Indeed, there are clear distinctions both in the field and from remote sensing data between LGM and pre-LGM deposits. We are therefore confident in LGM glacier outlines across Alaska for purposes of ELA reconstruction. While these glaciers may have reached their MIS 2 maxima asynchronously, available cosmogenic nuclide age constraints from moraine boulders (Supplement Fig. 2; Briner et al., 2005; Dortch et al., 2010; Matmon et al., 2010; Pendleton et al., 2015; Tulenko et al., 2018; Valentino et al., 2021; Young et al., 2009) and radiocarbon constraints (e.g., Child et al., 1995; Kaufman et al., 2003; Kaufman et al., 2012; Manley et al., 2001; Werner et al., 1993) indicate that this occurred within the timing of the LGM, further yielding credence to previous mapping."

LIA (page 9, line 6 – line 18)

"Present and LIA glaciation in Alaska beyond areas once influenced by the Cordilleran Ice Sheet are limited (Millan et al., 2022; Molnia, 2008). These include glaciers in the Ahklun Mountains, the central Brooks Range, the northern and western Alaska Range, and a lone glacier in the Kigluaik Mountains. During the LIA (dated to the 19th century in Alaska; Barclay et al., 2009), Alaskan glaciers deposited well-defined moraine systems downvalley of these extant glacier systems that remain relatively unvegetated and sharp crested (Evison et al., 1996; Kathan, 2006; Molnia et al., 2008; Sikorski et al., 2009; Reinthaler and Paul, 2023). Thus, we can calculate ∆ELAs (ELA_LIA – ELA_LGM) in valley systems where simple LGM glaciers were independent from large ice caps or ice sheets and within which there is clear geomorphic evidence of LIA glaciers. This precludes us from reconstructing ∆ELAs, however, where there is a lack of LIA glaciers, or where there is evidence of LIA advances, but the valley was covered by an ice cap or ice sheet during the LGM (i.e., much of the central Brooks Range and Ahklun Mountains)."

3. Spatial distribution of the LIA glaciers: the authors indicate that glacier reconstructions were produced for "selected valleys with well-defined LIA glaciers outlines" (p. 11), but it is unclear how these were chosen. Moreover, the limited spatial distribution of these LIA glaciers presents an issue in terms of the regional ELA assessments, as the LIA glaciers are limited to the Alaska Range, Kigluaik Mountains, and northeastern Brooks Range. Given the limited spatial distribution of the selected LIA glaciers, the ΔELA calculations should be restricted to the aforementioned localities. There is insufficient data to justify the state-wide ΔELA calculations, given that 90% (22 out of 24) of the LIA glaciers are located in the Alaskan Range.

This comment is very similar to a comment made by reviewer 1; these are great comments that we take very seriously. We have addressed this comment already above in this joint reply to all posted comments.

We changed text using 'statewide' in reference to our ∆ELAs to reflect our study area.

4. Uncertainties associated with asynchronous glacier maxima: a key uncertainty in regional ELA assessments is the timing of the ice masses reaching their maxima, and it is generally assumed that all the glacier maxima were reached synchronously. However, this is unrealistic, and the ice masses would almost certainly have reached their maxima diachronously. While it is not possible to quantify and account for this uncertainty, there needs to be some acknowledgement and discussion of this issue in the manuscript.

We added text in section 2 and a figure in the supplement (supplement Figure 2) showcasing available chronological constraints from cosmogenic nuclide measurements on moraine boulders as noted above.

We added text in section 5.3 (page 23, line 17 – page 24, line 5)

"Our paleo-temperature data provide evidence of relatively mild LGM climate in Alaska, confirming climate model output, and expanding information from the few sites with paleoclimate proxy data extending into the LGM. One may wish to consider whether the moraines from which we calculate LGM ELA values are all of the same age. Although many LGM terminal moraines in the state remain undated, we compile available cosmogenic nuclide age constraints from moraine boulders (Supplemental Fig. 2), which indicate that there is some variability in moraine age, but the dated moraines fall within the broad timing of the LGM. Furthermore, we suggest it likely that the spread in moraine ages relates to small-scale oscillations of LGM glaciers during the LGM period (and which one in each valley happened to become the outermost; Anderson et al., 2014) instead of significant spatio-temporal differences in LGM climate across the state. Thus, while we acknowledge that LGM moraine age may differ across the study area, we feel our ELA data still capture the LGM climate state."

Specific comments

p. 7, l. 13: I disagree with the statement that ELA reconstructions are a "labor efficient" approach to assessing regional palaeoclimate and that they are "more easily applied to a large region". While the ELA calculations themselves may not be time consuming, the process of glacier reconstruction *is* time consuming, especially when dealing with multiple ice masses across a large study area.

Yes, glacier reconstruction can be time consuming, but it is not as time consuming as glacier modeling. Thus, it is relatively *labor efficient in this context. We also added text to highlight the amount of work required before even beginning modeling or ELA reconstructions in section 2, (Page 6, lines 14 and 15).*

"Of course, both methods rely on immense amounts of chronology and field mapping required to designate accurate LGM alpine glacier limits."

p. 8, l. 11: "if" should be of.

Thank you for catching this.

p. 10, l. 23: did you apply a uniform basal shear stress value along the whole glacier flowline? Were variations in basal topography accounted for in the basal shear stress values?

Yes, we added text to clarify this:

"We calculated ice thickness every 25 m along these flowlines using GlaRe and a standard basal shear stress value of 100 kPa across all flow lines to ensure uniformity"

p. 11, l. 8: the AABR method is not one of the simplest methods of calculating ELAs, it is one of the more robust and sophisticated methods.

We deleted this statement.

p. 14, l. 5: why are there data for the LIA glacier systems (total numbers, distribution), but not for the LGM glaciers?

We chose not to delve into every range and sub-range for brevity.

p. 14, l. 8: why have you not plotted the LIA ELA data on a map, as for the LGM glaciers?

The main focus of this study was not the LIA ELA distribution itself, rather the ∆ELAs and temperature depressions. However, we will include this figure in the supplement that shows a map with LIA ELA values.

p. 14, l. 15: a general point regarding the use of the term "temperature depression(s)". I think it would be better to state "temperature differences" or similar, as the use of temperature depressions does not make any logical sense in this context. The LGM temperature cannot be depressed from the LIA because it occurred *before* the LIA (assuming that time is linear!).

We agree with the comment. However, 'temperature depression' phrasing is widely used by the community in ELA literature, so we decided to remain consistent with prior publications.

p. 14, l. 16 ff.: the text in the parentheses make this sentence difficult to read. Explanations of the error values reported would be better placed in the Methods section.

We moved this section to methods.

p. 14, l. 21: the ΔELA calculations should be restricted to the localities where there are LIA glaciers, as the limited spatial distribution of the LIA glaciers could skew the state-wide assessment.

We added text to eliminate the use of 'statewide'

p. 15, l. 2: as above, explain the errors in the Methods section.

We believe it's worth mentioning here again that we cannot have positive temperature depressions.

P, 15, l. 10 ff.: Section 5.1 is excessively long and could be streamlined substantially. Could you present some of the data in a table format and then synthesise the previous work? There is no need to describe each previous study individually.

We prefer to highlight and briefly discuss important previous literature and how the prior work compares to our results.

p. 15, l. 14–15: this compares ELA values at different scales. Why not directly compare the ELA values for the Brooks Range calculated in your study with those from Balascio et al. (2005)?

We added 'range' and put 'statewide' in parentheses.

p. 16, l. 2: it would be better to indicate that the THAR method has been superseded by more robust methods of ELA calculation.

We agree - thank you for the suggestion.

p. 17, l. 19–21: the independent clause after the colon is incomplete.

As far as we know, in American English, a dependent clause can follow a colon and an independent clause.

p. 19, l. 1 ff.: Section 5.3 is excessively detailed and could be streamlined.

Given the target journal, Climate of the Past, *we believe that thorough discussion of paleoclimate records are valuable for this manuscript.*

p. 22, l. 2: it is an overstatement to suggest that the ELA gradients are similar, given the very limited data for LIA glaciers outside of the Alaskan Range.

We qualified this statement by adding 'at least in the Alaska Range.'

COMMENT FROM DARREL KAUFMAN

Walcott et al. do an excellent job summarizing past work on Last Glacial Maximum ELA reconstructions in Alaska, and they present a new dataset of uniformly calculated ELAs from multiple mountain ranges across the state. Their resulting minor ELA lowering during the LGM and its implication for correspondingly relatively minor summer temperature reductions in this high-latitude region will be of interest to *Climate of the Past* readers.

I encourage the authors to further consider three aspects of their study:

(1) The authors place their findings in context of Arctic amplification, an important emergent feature of the climate system. However, Arctic/polar amplification is typically defined in terms of annual temperature, which can be related to the energy balance of the earth, whereas the glacier-based reconstructions are likely more strongly correlated with summer temperature. In order to make the link between the temperature reductions in this paper and those globally (i.e., Arctic amplification), it's important to compare annual to annual temperature. This is especially true because polar amplification is weak in the summer compared with other seasons, so comparing Arctic summer temperature with global annual can be misleading.

Rather than focusing on Arctic amplification, the authors might be better off comparing their Alaska summer temperature lowerings to those from the Atlantic sector of the Arctic and refocus the discussion on the longitudinal asymmetry and its possible causes. Alternatively, they might consider how their ELA-derived summer temperatures relate to annual temperatures so that they can more confidently discuss implications related to Arctic amplification. For example, assuming that seasonality is driven by orbitally controlled insolation, it's possible that temperature lowering during summer is a maximum estimate for annual changes.

Furthermore, previous studies of polar amplification during the LGM need to be considered. Polar amplification during the LGM is assessed in IPCC-AR6-WGI section 7.4.4.1.2. Based on the proxy data compilation in the report, LGM terrestrial air temperatures (Fig. 7.13f) and sea surface temperatures (Fig. 7.13i) from north of 60° latitude are not noticeably different than the global mean annual temperature (although they are variable). Some site-level LGM proxy records are even warmer than present. The glacier-based inferences in this study, albeit more strongly tied to summer temperature, agree with the IPCC's compilation, a point worth explaining.

Finally, the Arctic-wide average of -18 ± 7°C (Miller et al., 2010), which is cited on page 21, assumes that summer temperatures in Beringia were very low. Miller et al. featured the estimate from Elias et al. (1996) who concluded that Beringia summer temperature was 20°C lower during the LGM. While I agree that Alaska cooled less than over the ice-covered regions of the Arctic, it's rather misleading to use an Arctic-wide temperature estimate that assumes much lower temperatures for Beringia than are currently accepted, and that are the point of this paper. Instead, an important implication of this study is that the very low estimate of Arctic-wide LGM cooling needs to be updated.

We wish to express great thanks to all reviewers for taking the time to comment on our paper, and additionally to Dr. Kaufman for doing so unsolicited. We removed all references to Arctic amplification in the study, and instead focus more on comparisons between the North Atlantic and North America outside of Beringia. We included a reference to the IPCC report in Section 5.3 (page 24, lines 11 – 14).

"Similarly, a paleoclimate assimilation from the Intergovernmental Panel on Climate Change shows annual temperature depressions in parts of the Arctic similar to the global average suggesting that Arctic cooling was not zonally homogenous during the LGM (Forster et al., 2021)."

Ultimately, as Dr. Kaufman notes, it's important to compare summer temperatures with summer temperatures. Thus, unfortunately, this precludes many studies including that by Annan et al. (2022) from our comparison as they neither report summer temperatures nor have monthly or seasonal data available. We do, however, note that annual temperatures also show limited cooling in some parts of the Arctic in our discussion (page 24, line 6 – 14):

"Average summer global temperatures were ca. -6 ± 2.4 ºC lower during the LGM and were even lower in other parts of the high northern latitudes including much of northern North America and the North Atlantic (Osman et al., 2021; Tierney et al., 2020a). Our range of ∆ELA-derived LGM minimum summer temperature depression for Alaska of -3.4 ± 1.8 ºC, is similar to this global average, but higher than some summer temperature depressions in the northern high latitudes (Tierney et al., 2020a). Similarly, a paleoclimate assimilation from the Intergovernmental Panel on Climate Change shows annual temperature depressions in parts of the Arctic similar to the global average suggesting that Arctic cooling was not zonally homogenous during the LGM – both annually and in the summer (Forster et al., 2021)."

(2) I agree with the two anonymous reviewers that the study is missing ELA lowering estimates for multiple massifs where Little Ice Age glacier extent has been mapped and need to be added to this analysis for a more complete state-wide analysis. Easy pickings include the Ahklun Mountains, Kenai Mountains, and Brooks Range.

Thank you for reinforcing the other reviewer comments and for the suggestion for improvement. We have now, in responding to all comments, improved in this regard and we feel we do a better job at bringing in other LIA literature on Alaska.

(3) The paper would benefit from some sort of take-away figure (or maybe a table) that summarizes how the ELA-based temperature estimates compare with other paleoclimate

information discussed in the text. This could include key boundary conditions during the LGM, especially high-latitude summer insolation, which should be described someplace in the paper.

Thank you for the suggestion. Ultimately, given that we end with one average temperature depression, we do not think it necessary to create, what we believe, would be an extraneous figure. We believe we adequately provide the context for our results in the discussion section.

Minor comments:

Page 4 Line 22: Change “global data syntheses” to “data assimilation”, or more specifically, “blending of proxy-based sea-surface temperatures with a global climate model”. The warm Alaska temperatures in these products strongly reflect the choice of the model prior. This point is explored in detail in Annan et al.’s (https://doi.org/10.5194/cp-18-1883-2022) more recent data assimilation product for the LGM.

We changed the text here – thanks for the suggestion!

Page 5 line 8: Annan et al.’s LGM data assimilation includes terrestrial data. Also, it’s the underlying model that enables the spatial coverage of the DA reconstruction.

Thank you for pointing this out.

Page 5 line 13: “lack of terrestrial records” is an overstatement. Try, “limited availability” or similar.

We changed this.

Page 6 Line 16: Polar amplification is better defined as surface temperature at high latitude compared with the global average or sometimes hemispheric average, not the “mid-latitudes”.

We cut out our discussion of Arctic amplification.

Page 9 line 13-14: What are the specific “features of [these two] previously published studies” that this paper is building on?

These are the listed features in the following sentences.

Page 21 line 13: Where did this estimate (-5 ± 2°C) of summer temperature change come from?

This value is from Miller et al., 2010. However, we removed this text.

Page 21 line 15: While I agree that Alaska cooled less than over the ice-covered regions of the Arctic, it’s rather misleading to use an Arctic-wide temperature estimate that assumes much lower temperatures for Beringia than are currently accepted, and that are the point of this paper.

Please see our response to (1) above.

REVIEWER 3 - Andriano Ribolini

The paper presents an interesting synthesis of data from the ELA of the LGM and the LIA of Alaska, associated with the original ones reconstructed by the authors in some specific mountainous sectors.

The regionalization of the ELA is a delicate job because, differences in the method used for the calculation, uncertainties in the position of the frontal moraines, and subjectivity in the reconstruction of the surface of the past glacier, can introduce important biases in the final values, significantly invalidating the key interpretation paleoclimate.

In this paper the authors calculated the ELA on the basis of reconstructions based on numerical modeling anchored to glacial mechanics (GlaRe), and calculated the ELA in a systematically constant manner, arriving at discussing a dataset as robust as possible. The data density and spatial distribution over the Alaskan territory have therefore opened the door to insight palaeoclimatic discussions, although honestly acknowledging the points where uncertainties remain present (e.g. the lacking of a definitive mechanism for explaining the relatively warm summer temperatures).

The discussion of the data is skilfully proposed with a continuous comparison with results from different climate proxies (terrestrial and marine), which in the end gives the idea of a coherent palaeoenvironmental picture.

The figures are clear, I just suggest including some other geographical terms mentioned in the text (Gulf of Alaska, Bering Sea among others), for those who are not confident with the Alaska region.

Thank you - we are glad you thought our figures were clear. We added key geographical information to figure 1, per your suggestion.

I agree with other reviewers who indicate that more effort could be made to show how glacier extent data extracted from datasets (e.g. Alaska PaleoGlacier Atlas v2) were handled. From the text, it can be understood that they have been taken as they are, but perhaps some geomorphological checks have been made. I believe that some examples (accompanied by a figure for both LIA and LGM glaciers) could be added. Even how the chronological data was associated with glacial extensions could be further commented on. On these two points (glacial extents and their ages) the authors could also evaluate what kind of uncertainty they might have introduced in their dataset, and if this could ultimately be relevant.

We thank Dr. Ribolini for his review of our manuscript. All of his comments have been addressed in our responses to Reviewers 1 and 2.

Specific comments

I have no further specific comments that have not already been reported by other reviewers