

Replies to the review comments by Arindan Mandal on 'Reconstructed glacier area and volume changes in the European Alps since the Little Ice Age'.

by Johannes Reinthaler and Frank Paul

The manuscript presents a study of past glacier area, volume, and bed reconstruction for the European Alps, utilizing geomorphological feature identification and interpretation on high-resolution images, combined with historical topographic maps and current glacier boundaries. The results show that past glaciers have shrunk by over 50% in aerial extent, with more than 60% of their total volume lost between 1850 and 2015, which is consistent with a few previous studies in the region. Additionally, the authors estimate surface elevation of the LIA glacier extent (using an interpolation method they developed) and estimated elevation changes of the glaciers during the study period, and reported a tripling of thinning rates after 2000 compared to the overall long-term thinning rate.

In my opinion, the manuscript reconstructs and presents a crucial dataset of past glacier extents, which is vital for understanding long-term glacier behaviour in the Alps. The insights inferred from previous glacier fluctuations will also be invaluable for future glacier response modelling in the region. Considering the very high rates of glacier retreat and thinning in the Alps in the current era of climate change, understanding past rates is essential for planning mitigation strategies. Additionally, these datasets would be valuable to a range of scientific disciplines beyond glaciology, including hydrology, geohazard management, ecology, and others.

Overall, the manuscript is well-written in its different sections and concise in nature. The authors missed a few important references, as pointed out by community scientists, and they have promised to include these in the revised version. I do not have any major criticism. Below, I outline a few general comments and several minor suggestions for improvement. I recommend a minor to moderate level of revision before the manuscript's final online publication.

If any of my comments are unclear, please do not hesitate to contact me for further clarification.

[Thank you very much for the constructive review of our manuscript. It is nice to hear that the study is valued for its contribution to the understanding of long-term glacier changes.](#)

General comments

I did not find any discussion on the contrasting area/thickness/volume loss between the LIA and the current period in the western (high loss) and eastern Alps (low loss) regions. While the authors briefly touched on overall climatic conditions, there isn't a dedicated discussion on this topic, which would be valuable for understanding the influence of climatic shifts in these two contrasting (high/low loss) areas. If the authors do not plan to present a dedicated discussion, at least adding a few lines addressing climate changes in these regions, along with some basic statistics, would give readers a brief understanding of the influence of climate and its spatial variation across the European Alps, thus better establishing the connection between climate and glacier loss.

[We have actually not discussed climatic conditions, as the observed differences in area/volume changes are largely dependent on glacier size \(partly also hypsometry\) and making a connection to regional variability in climate change would be very speculative. We would also prefer not to discuss climate here in detail as we have not investigated this and think that the details of regional variability are rather complicated \(e.g. \[doi.org/10.1002/joc.1377\]\(https://doi.org/10.1002/joc.1377\)\), i.e. beyond the scope of this study. We would thus prefer to stay with the data we have derived rather than including more speculative parts. We will, however, add some more details on the differences in glacier changes between eastern and western Alps in the discussion.](#)

The authors might consider using the total uncertainty propagation technique from Mannerfelt et al. (2022). Reviewer 2 has raised concerns about the uncertainty estimation of volume changes in the current work, and I concur with these concerns. Mannerfelt et al. (2022; equation 9 in their work) used a similar dataset covering LIA outlines and varying temporal periods, which I think would provide valuable insights/guides for addressing the uncertainty issues in the current study.

[We appreciate the recommendation, but think that our uncertainty estimation is fitting better to our datasets, since we have used independent datasets from three specific sources from which we know their specific uncertainties. Please see also our response to Reviewer 1: "Thank you for the suggestion! You are right that the volume uncertainty is in the end related to uncertainties in glacier area and ice thickness, but in our study ice thickness is already a derived variable resulting from the independently derived glacier beds \(which we are just using\) and the glacier surface \(which we have reconstructed\). So, in our case we have to consider the uncertainties of glacier](#)

outlines (i.e. area) reconstructed by us, the uncertainty in elevation of the reconstructed glacier surfaces (which we also have calculated) and the uncertainty in the elevation of modelled bed topography (which we take from the related publications). As these are the three independent sources of uncertainty to be considered, we think our way of calculating volume uncertainty is correct.

Line-by-line comments

L14: Here, I would have mentioned the latest year instead of ‘today,’ as in future years, the term ‘today’ will lose its relevance.

We wrote now ‘around 2015’ instead of ‘today’.

L17: I would prefer ‘On average’ (which sounds better I think!) instead of ‘In the mean’?

Done.

L32: ‘trim lines’ and trimlines (in abstract; L11; also in L40, and elsewhere) needs to be consistent across the manuscript. Also, I think, as the authors have already expanded LIA in the abstract, they should not need to re-expand it. Please check with the journal’s guidelines.

We have checked the consistency of trimlines vs trim lines and now use trim... All acronyms have to be repeated in the main text as required by the journal guidelines.

L39-40: I think this sentence is incomplete. Did the authors mean ‘ between 1350 and 1850/60, with the exact timing depending on the glacier’? Please check.

Correct, thank you for pointing this out. We have changed the text accordingly.

L78-80: Here, I would be happier to see ‘the range of resolutions’ for the very-high-resolution images those were used for interpretation/delineation.

We have added the resolution.

L82-83: Which study provides the outlines from 1967-1971 for France? The authors might consider citing the reference here for the readers’ quick knowledge.

We have now added the reference.

L103-105: This modern DEM refer to 10 m Copernicus DEM? Right. Re-mentioning might be helpful for the readers.

Yes, agreed. We have slightly rephrased the sentence.

L105-106: Is this ‘Topo to Raster’ a tool for interpolation or a known method? Not clear from the current sentence? Please clarify.

It is the name of a tool in the ESRI software package. We have now clarified it and included a reference.

L107-108: The authors mean ‘The output result..’, right?

Yes, indeed. Changed.

L153: Please expand SLR here, for the readers’ sake.

We have changed it.

L176-177: Here, please mention the range of the elevation changes, for further information to readers. Also, here, ‘highest changes’ sounds a bit awkward as the value is the most negative (lowest), so I would suggest something like ‘highest mass loss/thinning’?

We have added elevation change details and changed ‘highest changes’ to ‘highest thinning’.

Table

Table 1: I would suggest the authors to mention the time period of P1-P2 for clear information in the table caption.

We have added the information to the table caption.

Figures

Figure 3: Are the volume change rasters (subplot d) aggregated to a specific grid size? If so, please mention it.

We have added the grid size (4 km).

Figure 5: By looking at the panel b and the color contrast of elevation changes, it seems the change values are

even lower than -2 m/y, if I am not wrong. The authors need to re-draw the colorbar or add extend marks.
We have changed the colour bar labels since also values smaller than -2 all have the same colour.

Figure 6: Here, in panel b, the color scheme of the colorbar may not be ideal, given the range of +23 to +123 (only increasing side everywhere). A single color gradient, where the darkest shade represents the highest increase and the lighter shades represent the lowest values, might be more appropriate.
Yes, agreed. We have changed the colour bar.

Figure S6: I would suggest the authors to label the sub-plots by citations (e.g., Sommer et al., 2020, etc.) and by the time period of the elevation change estimate. Also, same in and S10.
Yes, this could be done, but we think the information is now also well accessible. We would thus prefer to keep the two figures as they are.

References

Mannerfelt, E. S., Dehecq, A., Hugonnet, R., Hodel, E., Huss, M., Bauder, A., and Farinotti, D.: Halving of Swiss glacier volume since 1931 observed from terrestrial image photogrammetry, *The Cryosphere*, 16, 3249–3268, <https://doi.org/10.5194/tc-16-3249-2022>, 2022.