

Clim. Past Discuss., referee comment RC1
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Review of "Atmosphere-Cryosphere interactions at 21 ka BP in the European Alps" by Del Gobbo and al.

Anonymous Referee #1

Referee comment on "Atmosphere-cryosphere interactions during the last phase of the Last Glacial Maximum (21 ka) in the European Alps" by Costanza Del Gobbo et al., *Clim. Past Discuss.*, <https://doi.org/10.5194/cp-2022-43-RC1>, 2022

This paper presents a new regional climate model (RCM) of the European Alps during the Last Glacial Maximum (LGM, about 21'000 years ago) at a resolution of 12 km. Based on the new RCM, the authors revisit the cryospheric LGM state in terms of glacier extent. The goal here is to use climate modelling to investigate former glaciations in the Alps and complete our knowledge based on geological findings (e.g. based on the analysis of landforms such as moraines). The LGM precipitation pattern inferred by the authors is valuable to understand the global atmospheric circulation prevailing in the Northern Hemisphere during the LGM as it was hypothesized that the shift of the polar front (due to the presence of massive ice sheets over the American continent) must have changed storm track trajectories, and modified dominant moisture advection over the Alps, with substantial impacts on the building of glaciers in the Alps (e.g., Luetscher and al., 2015). The link between precipitation pattern (and more generally the entire climate dataset) and geologically-based glacier reconstructions is analyzed and discussed in the paper.

Climate modeling has a great potential to improve our understanding of climates of the past -- during key periods such as the LGM -- and their impact in terms of glaciations. This potential has hardly been explored to date. Therefore, I believe this study is a valuable and original contribution in the field. Overall, I found the paper interesting, well-structured and well-written (despite several typos). As I'm not a climate scientist, I can hardly judge on the methodology to infer climate. Therefore, my comments -- listed below sorted by decreasing importance -- are focused on the glaciological analysis. My main concern is about the comparison of the inferred environmental ELA to geologically-reconstructed glacier outline, which currently does not evidence a significant fit I think. Similarly, there are statements in the text that are not (or hardly not) supported by clear evidence in Figure/results. Lastly, I think the authors should discuss the limitations of the environmental ELA method that infer glacier information from climate, as the approach is highly simplified regarding the complexity of glacier processes. I hope that my comments help the authors improve the manuscript.

Main Comments}

- Section 2.4, the computation of the envELA is obscure to me, it should be clear without having to go to the paper from Zebre and al. (2020). (e.g. say clearly that envELA is the theoretical altitude where glaciers can be sustained; I had to go to Zebre and al. (2020) to find it, or maybe I missed it.) I understand Eq. (4), but why do we need Eq. (3)? The RCM gives mean summer temperatures, so I don't understand why you need to compute it via (3). Another very important point is: what is the DEM you use? is it present topography or a LGM reconstruction of the surface (including glaciers)? This is crucial missing information.
- 216 to 221 and Figure 5: you argue that you can assess your modeled climate against the reconstructed glacier outline by comparing the envELA with the model topography. I agree with this. However, I do not see any convincing figure that supports it because only the envELA is displayed in Fig 5, and never the model topography. Also, it is not clear to me what topography you compare -- I assume the LGM topography. Also I found that displaying the colors of the ELA only within the mask derived from Ehlers and al. (2011) is misleading, as it gives the wrong feeling of a fit. Why don't you simply draw the contour of envELA minus LGM DEM (they exist geologically-based reconstructions, e.g. in Switzerland by Bini and al (2009)), and compare the zero-level line to the maximum glacier extent of Ehlers and al. (2011)? An important issue with this paragraph is the lack of supporting figure. I encourage the authors to go over all the statements of the discussion, and to make sure that all of them refer to Figure, Table, or papers.
- Following my previous comment, I think that comparisons between your model results to geologically-based reconstructions (e.g. from Ehlers and al. (2011)) is way more important than comparison with modeling studies based on the Parallel Ice Sheet Model (PISM) from Becker and al. (2016) or Seguinot and al. (2018). Indeed, it is far from obvious to compare your results to the one from PISM as i) your climate forcing is very different and more funded than the simple distortion of present-day climate used in PISM studies ii) PISM is very different and more funded to compute the glacier response from a climate than the environmental ELA. Therefore, it is difficult to distinguish which from i) or ii) is mainly responsible for discrepancy between your results and the PISM-based ones. Instead, I would encourage the authors to focus further on comparisons with purely geologically-based reconstructions.
- 242-247: This statement is not supported by any figure or table of the paper.
- 254: "where our envELA shows a drop consistent with the geological reconstruction": again this statement is not supported, or if I missed it, you should clearly indicate what figure you are referring, and ideally, make sure the caption permits to link the statement to evidence on the figure.
- Unless I missed it, I see no or very little discussion on the limitation of your approach to interpret climate data into glacier information. Yet, the inference of the envELA, and its interpretation in terms of glacier coverage, relies on strong assumptions such as ignoring dynamical and transient aspects of climate and glaciers. Just one example: Knowing the LGM climate is important, but the duration of the latter has prevailed is equally important for shaping glacier: For example, under the same climate, Rhone Glacier would need a longer time period to reach its known LGM extent than Rhine Glacier because the latter is smaller (in term of drainage basin) and has less inertia. Therefore, the transient aspect of climate is also very important to explain glacier footprints. Of course, this cannot be evidenced with the steady-state assumption. But this illustrates why elaborating further on the limitation of your method is needed I think.

Minor comments

- Title: suggest writing Last Glacial Maximum instead of 21 ka BP \item Abstract: Second sentence: suggest changing "affected" by "controlled"
- Abstract: Third sentence: "physical processes" may be overstated as the interpretation of the climate in terms of glacier extent lacks number of glacial processes (e.g. transiency/dynamical aspects), consider rephrasing.
- l 23: ... is considered \textbf{to be} a global event ...
- l 27: "ice stream" usually refers to fast flow ice, not sure this is appropriate here.
- l 31, north and \textbf{west} (Rhône, Lyon) \item l 39: mountain glaciers \textbf{worldwide} ...
- l 42: 3 to 6 sounds not much. Augmenting the literature will enlarge the range. For example, you may include the paper by Tierney and al. 2020 in Nature (Glacial cooling and climate sensitivity revisited).
- l 58 "widely studied" calls for references
- l 74: there is something strange with the citation (Zebre et al. 2020), please fix it.
- l 83: I don't think you have introduced the acronym PI before, I assume it is Pre-Industrial?
- section 3.3, title, add this is the Regional model
- It would help to have a figure showing the result of the large-scale climate simulation (section 3.2), e.g. to visualize the 9°C cooling or -30% reduction of precipitation.
- l 190: "the two glaciers are mainly \textbf{interested}..." is a strange formulation
- l 209: PI ELA at 2435 m sounds low to me, what does the literature say?
- l 249 in a previous study: you may cite Visnjevic and al. (2020).
- l 270: what is this (8)?
- l 280: Baker is Becker, please correct everywhere in the text.
- l 361: some discrepancies: can you be more specific? what discrepancy? what study?
- l 361-369: looks like a conclusion
- l 379: typo, remove the space before the dot.
- l 383: typo; agreement