Response to Reviewer 2 (Anonymous)

Reviewer's comments are repeated in black. Authors' replies are highlighted in blue font and the revised text in the manuscript is in quotation marks with blue italics font.

The study by Boateng et al explored the application of water isotope tracking enabled AGCMs to simulate climate and precipitation d18O responses to different uplift scenarios of the Alps with the goal to identify potential imprints in d18O that can be used to reconstruct paleo-elevations of this orogen. The manuscript is pretty easy to follow, and the results are straightforward and interesting.

My main suggestion is that the analysis of the influences of different elevation scenarios of Alps on the modes of decadal pressure variability can be better linked to the precipitation and trajectory analysis. In geological archives, you will only see changes of the mean states of precipitation and d18O given the loose temporal resolution and signal averaging in records. If the decadal variability in pressure fields were to affect the mean state of precipitation and d18O, it needs to incur asymmetric responses of precipitation and/or moisture transport paths between positive, neutral, negative phases of those modes of variability. Alternatively, you could cut out this part of the analyses, which seemed to be independent from the rest of the analyses anyway.

We thank the reviewer for their time and the constructive comments highlighted to improve the manuscript. The reviewer raises a very valid point for their main suggestion. In fact, we agree that the changes in the atmospheric mode of variability would not be reflected in the low temporal resolution of the geologic archives. However, we performed such analysis to determine if the topography of the Alps can somewhat affect such large-scale circulations. Since European climate variability and moisture transport to the continent are mainly driven by such circulation patterns, it is worth investigating if having representative topographic scenarios would drive the seasonal and spatial distribution of $\delta^{18}O_p$ in a different way than in the present-day climate. Methner et al., 2020 suggested that the reorganization of the mid-latitude atmospheric circulation resulted in seasonal changes in the timing of carbonate formation across Central Europe in the Middle Miocene. As much as the global climate would drive such changes, such an analysis highlights the role the topography across the Alps can play in changing these circulation patterns. We have clarified this in the text in lines 648-655.

"However, we do acknowledge that changes in such a decadal mode of variability would not be reflected in such low resolution of geologic archives used for stable isotope paleoaltimetry. Nevertheless, assessing the role of topography in changing the atmospheric dynamics of such large-scale circulation patterns sheds light on the possibility of its impact on the spatial variability and distribution of $\delta^{18}O_p$. For instance, this has been highlighted by Methner et al., (2020) on the possibility of the reorganization of the mid-latitude atmospheric circulation in the Middle Miocene that led to the seasonal changes in the timing of carbonate formation across Central Europe."

More detailed suggestions:

1. Line 90, change "This" to "This event".

2. Line 95, change “These” to “These processes”

3. Line 98, change “slab break-off is suggested to have occurred” to “it has been suggested that slab break-off occurred under...”

4. Line 99, “suggest” is used twice in a sentence, change to “argue”

5. Line 100, change “considers” to “focuses on”

6. Line 106, change “the eastern Alps initiated their” to “orographic development of eastern Alps initiated during the...”

7. Line 110 to 111, “Reconstruction for the central Alps” change to “Reconstruction of the central Alps paleo-elevation”

8. Line 136, remove “recent”. Some of the knowledge has been around for quite a while.

All of the above points (1-8) have been corrected as suggested.

9. Line 142, please see Feng et al., (2016, EPSL) for the “Previous studies have used GCMs to perform topographic sensitivity experiments…” as well.

We thank the reviewer for the additional references. We have added it to the list.

10. Line 165 to 170, how was the subgrid scale topographic variability treated in those topography sensitivity experiments?

We thank the reviewer for raising such a concern. We modified the GTOPO30 Digital Elevation Model provided by the U.S. Geological Survey, which has a resolution of 30-arc seconds (ca. 1 km). Afterward, the modified high-resolution DEMs are interpolated to the ECHAM5-wiso model resolution. The associated relevant subgrid orographic variables are calculated from the higher-resolution DEM. These include variables such as the orographic standard deviation (i.e., the variability of the heights of the mountain range), anisotropy, peak elevations, valley elevations, mean slope, and orientation within a grid cell. Such related information is used for the subgrid-scale parameterization that estimates the effect of mountain-induced wave drag on the atmosphere and mountain blocking in the model (Stevens et al., 2013; Roeckner et al., 2003). We extend section 3.2 with additional sentences to clarify how the sub-grid topographic variability was treated (in lines 185-192).

"The topographic boundary conditions for the different experiments are prepared as follows: We modify the GTOPO30 Digital Elevation Model provided by the U.S Geological Survey, which has a resolution of 30-arc seconds (ca. 1 km). Afterward, the modified high resolution DEMs are interpolated to the ECHAM5-wiso model resolution. The associated subgrid orographic variables are calculated from the higher resolution DEM. These variables include orographic standard deviation (i.e., the variability of the heights of the mountain range), anisotropy, peak elevations, valley elevations, mean slope, and orientation within a grid cell. Such related information is used for the subgrid-scale parameterization that estimates the effect of mountain-induced wave drag on the atmosphere and mountain blocking in the model (Stevens et al., 2013; Roeckner et al., 2003)."

11. Line 195 and Table 1, it is hard to visualize different scenarios of topographic evolution through time, it would be very helpful to turn this table into a topographic evolution diagram with respect to different time intervals.

We thank the reviewer for pointing this out. The topographic configuration tested through these sensitivity experiments represent plausible scenarios due to the limited quantitative paleoelevation estimates across the Alps. Moreover, the geodynamic evolution of the Alps that could shed more light on the different topographic evolution is still under debate (e.g., Schmid et al., 1996; Handy et al., 2010). Therefore, we simply conduct sensitivity experiments and aim to explore the feasibility of future paleoelevation altimetry estimates that would contribute to the understanding of the geodynamics evolution of the Alps.

12. Line 228, expand "statistical significance of these differences" into "statistical significance of these differences against simulated interannual climate variability"

This has been corrected.

13. Line 300, change "changes in the …" to "changes of d18Op in the…"

This has been corrected.

14. Line 340, "<80 mm/month", how much precipitation is that?

This has been changed to the range of simulated difference which is 50-80 mm/month.

15. Line 522 to 524, see Feng et al., (2016) for non-adiabatic temperature responses simulated in the Eocene North American Cordillera.

We thank the reviewer for the additional reference that supports our discussion. We have added it to our list.

16. Line 625 to 626, it may worth mentioning that the configuration of paleo-Tethys would likely make a difference in whether there is "Mediterranean" moisture input or not.

We thank the reviewer for highlighting this. In the region of the Alps, the Paleo-Tethys fully subducted during the Mesozoic. The successive opening and closure of the Piemont-Ligurian and Hallstatt-Melita oceans led to the Alpine orogeny, but given that they had fully subducted by the Middle Miocene, we believe that the reviewer is referring to

Paratethys and its climatic effects. We have extended the sentence to include the potential influence of the closure of the Paratethys Sea on moisture transport (lines 665-673).

"Nevertheless, the Late Cretaceous to Paleogene closure of the Tethys Ocean, which lead to the surface uplift of the Alps might influence the transport of moisture from the Mediterranean in a past climate. Botsyun et al. (2022) simulate the global climate with middle Miocene paleoenvironment conditions while considering the Paratethys Sea extent in their land-sea mask to determine the impacts of the marine transgression on the regional climate. Their results indicate an increase in precipitation up to 400 mm/yr around the regions adjacent to the Paratethys Sea with anticyclonic circulation situated over the Mediterranean in the winter season. Note, however, a fully coupled ocean-atmosphere GCM model would be needed for a realistic assessment of the contribution of ocean circulation to the distribution of $\delta^{18}O_p$ patterns across Europe."

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