RESPONSE TO RC2 Anonymous Referee #2

We thank referee 2 for their comments. Our specific responses are given below (in blue italic) and changes in wording are indicate in normal blue script.

1. The authors make an intriguing observation about the delay in peak summer warming in their own reconstructions, which they suggest might be attributed to the presence of the Laurentide and Fennoscandian ice sheets. While this hypothesis is plausible, it is crucial for the authors to discuss the limitations and uncertainties of the models used, as the simulations didn't accurately represent the timing and magnitude of ice-sheet and meltwater forcing, especially regarding the Fennoscandian ice sheet.

We agree that it is important to comment on the limitations and uncertainties associated with the model experiments. We addressed this in our original Discussion (lines 346 to 352) by pointing out that while both the TRACE-2112K-II and the LOVECLIM simulations included the relict Laurentide and Fennoscandian ice sheets, they did not incorporate realistic ice sheet and meltwater forcing. We also pointed to the Kapsch et al. (2022) which shows that differences in ice sheets and meltwater forcing are implemented cause differential sensitivity to the presence of these relict ice sheets. However, we have expanded the text to make this clearer, as follows:

Reconstructed MTWA shows a gradual increase through the early Holocene with maximum values of around 1.5°C greater than present reached at ca 4.5 ka. Previous modelling studies have shown that the timing of maximum warmth during the Holocene in Europe was delayed compared to the maximum of insolation forcing and varied regionally as a consequence of the impact of the Fennoscandian ice sheet on surface albedo, atmospheric circulation, and heat transport (Renssen et al., 2009; Blascheck and Renssen, 2013; Zhang et al., 2016; Zhang et al., 2023). Two of the simulations examined here show a delay in the timing of peak warmth, which occurred ca 9 ka in the TRACE-21k-II simulation and ca 7.5 ka in the LOVECLIM simulation. Although both sets of simulations include the relict Laurentide and Fennoscandian ice sheets, neither has realistic ice sheet and meltwater forcing. In the LOVECLIM simulation, for example, the Fennoscandian ice sheet was gone by 10 ka whereas in reality it persisted until at least 8.7 ka (Patton et al., 2017). Thus, the impact of the Fennoscandian ice sheet in delaying orbitally induced warming would likely have been greater than shown in this simulation. In addition to differences in the way in which ice sheets and meltwater forcing are implemented in different models, models are also differentially sensitive to the presence of the same prescribed ice sheet (Kapsch et al., 2022). Thus, it would be useful to examine the influence of more realistic prescriptions of the relict ice sheets on the climate of the EMBSeCBIO region using multiple models, and preferably transient simulations at higher resolution or regional climate models. It has been suggested that meltwater was routed to the Black and Caspian Seas via the Dnieper and Volga Rivers during the early phase of deglaciation (e.g. Yanchilina et al., 2019; Aksu et al. 2022; Vadsaria et al., 2022) and it would also be useful to investigate the impact of this on the regional climate.

2. The use of model simulations serves as an important component of this manuscript, providing a means for extrapolating and understanding the potential drivers behind the observed climate trends. The authors might need to provide a more thorough explanation about the discrepancies in the trend of plant-available moisture, α, between the models. They state that the differences likely reflect changes in atmospheric circulation, but don't discuss more what those changes might be, or why

the models differ in their representation. This warrants a more detailed explanation or at least a call for future research to address this discrepancy.

Please note that the reconstructed changes in plant available moisture were affected by a mistake in the inputs used in the CO2 correction and this has now been corrected in the revised manuscript (see response to comment by Chris Brierley above). It is beyond the scope of this paper to determine why the various models show different trends in moisture availability through time. In the original text, we pointed out that climate models have difficulty both in simulating moisture transport into Europe and in capturing the land-surface feedbacks associated with changes in moisture availability. Differences in model configuration and parameterisations underpin both of these problems, but it would be difficult to determine this without sensitivity experiments. Our point here is that the differences between the modelled trends, and the relatively small simulated changes in the late Holocene, mean that the reconstructed changes in plant-available moisture cannot be simply a function of orbital forcing - which would tend to cause similar trends across the models. We have tried to make this clearer in the discussion as follows:

We have shown that α was similar to today around 11 ka, but there was a rapid increase in moisture availability after ca 10.5 ka such that α values were noticeably higher than present between 10 to 6 ka, followed by a gradual and continuous decrease until the present time. Changes in the late Holocene are small even at centennial scale (Figure 5). The reconstructed trends in α are not captured in the simulations, which show different trends during the late Holocene. Thus, it is unlikely that the gradual increase in aridity during the late Holocene is a straight-forward response to orbital forcing. Changes in α in the EMBSeCBIO region are likely to be primarily driven by precipitation changes, which in turn are driven by changes in atmospheric circulation. Differences in the trend of moisture availability between the models imply that the nature of the changes in circulation varies between models and thus the simulations do not provide a strong basis for explaining the observed patterns of change in moisture availability. Earlier studies, focusing on the western Mediterranean (Liu et al., 2023), Europe (Mauri et al., 2014) and central Eurasia (Bartlein et al., 2017), have shown that models have difficulty in simulating the enhanced moisture transport into the Eurasian continent shown by palaeoenvironmental data during the mid-Holocene and during the late Holocene. Changes in precipitation can also affect land-surface feedbacks. Liu et al. (2023), for example, have argued that enhanced moisture transport into the Iberian peninsula during the mid-Holocene led to more vegetation cover and increased evapotranspiration and had a significant impact in reducing growing season temperatures. Differences in the reconstructed trends of summer temperature and plant-available moisture through the Holocene suggests that this land-surface feedback was not an important factor influencing summer temperatures in the EMBSeCBIO region. Nevertheless, differences in the strength of land-surface feedbacks between models could also contribute to the divergences seen in the simulations. It would be useful to investigate the role of changes in atmospheric circulation for precipitation patterns during the Holocene in the EMBSeCBIO region using transient simulations at higher resolution or regional climate models.

3. The authors also allude to the potential implications of their findings for understanding shifts in population density and cultural changes but do not expand upon this. It would be interesting to explore these implications further in the discussion, or in future work.

We take this comment as an opportunity to expand on the potential implications of our reconstruction, particularly of our reconstruction of plant available moisture, for the origin of the agriculture in the region that lead to the expansion of population. In the discussion section, We have added the following paragraph in the discussion:

The timing of the transition to agriculture in the eastern Mediterranean is still debated (Asouti & Fuller, 2012). It has been argued that climatic deterioration and population growth during the Younger Dryas triggered a shift to farming (Weiss & Bradley, 2001; Bar-Yosef et al., 2017). The presence of morphologically altered cereals by the end of the Pleistocene has been put forward as evidence for an early transition to agriculture (Bar-Yosef et al., 2017), but it has also been pointed out that the evidence for cereal domestication before ca 10.5ka is poorly dated and insufficiently documented (Nesbitt, 2002) and that crops did not replace foraging economies until well into the Holocene (Smith, 2001; Willcox, 2012; Zeder, 2011). The availability of water is a crucial factor in the viability of early agriculture (Richerson et al., 2001; Zeder, 2011). We have shown that moisture availability was higher than today during the first part of the Holocene (10-6 ka) but similar to today until ca 10. 5 ka. Wetter conditions during the early Holocene could have been a crucial factor in the transition to agriculture, and our findings support the idea that this transition did not happen until much later than the Younger Dryas or late glacial/Holocene transition. Further exploration of the role of climate in the transition to agriculture would require a more comprehensive assessment of the archaeobotanical evidence. The issue could also be addressed using modelling to explore how the reconstructed changes in regional moisture availability and seasonal temperatures would impact crop viability (see e.g. Contreras et al., 2019).

Contreras, D.A., Bondeau, A., Guiot, J., Kirman, A., Hiriart, E., Bernard, L., Suarez, R., Fader, M.: 2019. From paleoclimate variables to prehistoric agriculture: Using a process-based agro-ecosystem model to simulate the impacts of Holocene climate change on potential agricultural productivity in Provence, France, Quat. Internat., 501, 303-316.

4. While the authors have made efforts to correct for past CO2 changes, it would be beneficial to have a more detailed discussion about the potential implications of recent anthropogenic climate changes and their impacts on the trends identified in the study.

Although we have not explicitly discussed the direct effect on anthropogenic changes in CO_2 on the reconstructions, it is essential to note that the CO_2 correction method already takes into account recent increases in atmospheric CO_2 levels. As described in the Prentice et al. (2022) model, the correction accounts for changes in water use efficiency in response to elevated CO_2 levels, leading to a more efficient water utilization by plants under current atmospheric conditions. To make this point clearer in the paper, we have modified the description of the correction procedure as follows:

We applied a correction factor (Prentice et al., 2022) to the reconstructions of α to account for the impact of changes in atmospheric CO_2 levels on water-use efficiency, specifically the increased water use efficiency under high CO_2 levels characteristic of the recent past and the low CO_2 levels that would have reduced water use efficiency during the late glacial and thus could have influenced the reconstructions during the earliest part of the records.

5. The discussion section seems to be a heavy focus on comparing their findings with those of Mauri et al. (2015) and Herzschuh et al. (2022). While these comparisons are important, incorporating a broader range of studies would enrich the analysis and give readers a more comprehensive understanding of the state of research in this area.

While there is a rich literature on palaeoenvironmental changes in the region, the only quantitative reconstructions currently available are those of Mauri et al. (2015) and Herzschuh et al. (2022). Our reconstructions are based on an improved data coverage and, we believe, a more robust methodology. We feel it is important to compare these reconstructions with previous reconstructions to highlight similarities and differences. Comparisons with the more qualitative palaeoclimate interpretations from individual sites would considerably expand the length and alter the focus of the paper.

Minor comments.:
In Fig5-Fig7, the y-axis should include lowest/highest value, for example, L215 mentioned about 8°C lower, but y-axis only has 7.5°C.

We have expanded the number of intervals on the scales, ensuring that they encompass both the minimum and maximum values of the smoothed mean, and using whole numbers exclusively. Please see response to a similar comment above.

Line 223, "There was a gradual decrease in temperature after 5k", but in Fig.5 the decrease starts from around 4k.

The pivotal moment in MTCO happens around 5ka, whereas in MTWA and GDD0, it takes place slightly later, closer to 4.5ka. Due to the uncertainty surrounding these dates, we have employed the prefix "circa" (ca) to indicate approximate timings. Nonetheless, we acknowledge that we haven't maintained this consistency throughout the entire text. To rectify this, we have replaced "5ka" with "ca. 4.5 ka."

Line 796, Fig5, "The green line..." should be "The blue line"

We have now amended this.