

## Response to Reviewer 1

1. line 34 'Projections of future climate change suggest that the region will become both warmer and drier, but nevertheless show that this west-east differentiation is maintained.' Reference(s) is needed here.

There was some confusion here because we cited one of the Andrade et al. papers that deal with projections later, but we should have cited another paper at this point. We have added a reference to Andrade et al. (2021) which specifically shows the west-east gradients in RCP scenarios.

Andrade, C., Contente, J. and Santos, J. A.: Climate change projections of aridity conditions in the Iberian Peninsula, *Water*, 13(15), doi:10.3390/w13152035, 2021a.

2. line 16. 'early to mid-Holocene' Here, and in other instances in the text, the authors use terms like mid-Holocene, early Holocene, present, without having defined them explicitly. In particular, the reference to 'present' is relevant, and the manuscript often assesses Holocene temperatures compared to 'present temperatures'. Is 'present' the 20<sup>th</sup> average, pre-industrial, around 1950, temperatures?

The terminology for early Holocene and mid-Holocene is not clear. We did define the mid-Holocene as 8-4 ka (line 42), and since this is the period we are referring to in terms of the change in west-east gradient, we have modified the abstract to "mid-Holocene". Our comparisons to the present day are based on the comparing each bin to the most recent bin (0.5 ka  $\pm$  500 years); we have clarified this now in the text.

3. line 49 'Although these records are extensive, they seem to indicate fairly complex spatial patterns of change# I did not understand why the word 'although' needs to be used here. I do not see an implicit contradiction between being extensive and showing complex spatial patterns.

Indeed there is no contradiction. We have changed this to "These records are extensive and they seem to indicate fairly complex spatial patterns of change. "

4. line 53. Peninsular

We have now changed this to

"However, most of the ca 50 sites from Iberia were from the Pyrenees and the inferred patterns across the remainder of the Iberian Peninsula are therefore largely extrapolated."

line 53 'Furthermore, quantitative reconstructions of summer temperature made at individual sites using chironomid data (Muñoz Sobrino et al., 2013; Tarrats et al., 2018) are not consistent with reconstructed changes based on pollen for the same sites.' with reconstructed temperatures. Otherwise the sentence is grammatically somewhat odd.

Thank you. We have changed this as suggested to:

" Furthermore, quantitative reconstructions of summer temperature made at individual sites using chironomid data (Muñoz Sobrino et al., 2013; Tarrats et al., 2018) are not consistent with reconstructed temperatures based on pollen for the same sites. "

5. line 60 'We analyse how these trends are related to external forcing' I think the authors refer here to external climate forcing, but the sentence could be misinterpreted as meaning remote forcing, e.g. from the North Atlantic.

Yes, we do indeed mean external climate forcing and have changed the sentence to read:

" We analyse how these trends are related to changes in external climate forcing and quantify whether there are significant differences in west-east gradients through time. "

6. line 93 'We excluded individual pollen samples with large age uncertainties (standard error larger than 100 years)' What is the typical time resolution of the reconstructions? I think it is nowhere stated.

We are referring here to the standard error on the ages, but since this is not clear we have modified the sentence to read:

We excluded individual pollen samples with large uncertainties (standard error larger than 100 years) on the attributed age in the new age model.

We have also added a sentence here to specify the average resolution of the records:

As a result, the climate analyses are based on a fossil data set of 7121 pollen samples from 117 sites covering part or all of the last 12,000 years (Figure 1). The average temporal resolution of these records is 101 years.

7. line 105 'and assessed the significance of differences in these trends through time compared to 0.5 ka based on p values' compared to 0.5 ka? It is for me unclear.

We compared the 1000-year binned Holocene records to the 0.5 ka bin (0~1 ka) in order to avoid problems with post-industrial climate changes including recent anthropogenic changes in climate. In fact, it makes little difference to the detection of when the trends are different. We will clarify the choice of 0.5 ka as follows:

"..... and assessed the significance of differences in these trends through time compared to the most recent bin (0.5 ka  $\pm$  500 years) based on *p* values ...."

8. line 141 'Summer temperatures are strongly correlated with changes in  $\alpha$ ' spatially or temporally correlated?

Both. Figure 5a shows correlations in the modern data set, and therefore reflects spatial correlations. Figure 5b shows correlations across the fossil samples and therefore shows spatial and temporal correlations. We will modify the sentence to clarify this as follows:

"Summer temperatures are strongly correlated with changes in  $\alpha$ , both in terms of spatial correlations in the modern data set at a European scale and in terms of spatial and temporal correlations the fossil data set from Iberian Peninsula (Fig. 5)."

9. line 158 'their reconstructions show a cooling of 3°C in the early Holocene are comparable in magnitude# I guess that 'are' should be deleted.

Thanks for pointing this out, we have deleted this "are".

10. line 165 'change at some of the individual sites is much larger (ca 10°C) and there is no assessment off the uncertainty on these reconstructions. ' of

Thanks for pointing this out, we have corrected this typo.

11. line 193 'However, they show a persistent cooling of 1.5 °C compared to present between 4.5 and 2 ka, not seen in these reconstructions' do the authors mean persistent cooling trend or persistent cool conditions?

We meant persistently cool conditions. We have modified the sentence to make this clearer, as follows:

"... they show persistently conditions cooler than present by ca 1.5 °C between 4.5 and 2 ka, ..."

12. line 214 'Specifically, the increased advection of moisture into eastern Iberia created wetter conditions leading to increased evapotranspiration, less allocation of available net radiation to sensible heating, and resulting in cooler air temperatures.' I think the authors' point is not necessarily that increased evapotranspiration leads to colder temperatures, but rather to less temperature variations through time and space. The study suggests that summer temperatures did not fall as expected from the solar insolation alone, so this sentence is a bit confusing. Please, clarify.

We have shown that there is a change in the west-east gradient of moisture which implies that there is increased moisture advection into the eastern part of the Iberian Peninsula. Here we were trying to provide an explanation of how this would impact summer temperatures. We have rewritten the sentence to clarify this, as follows:

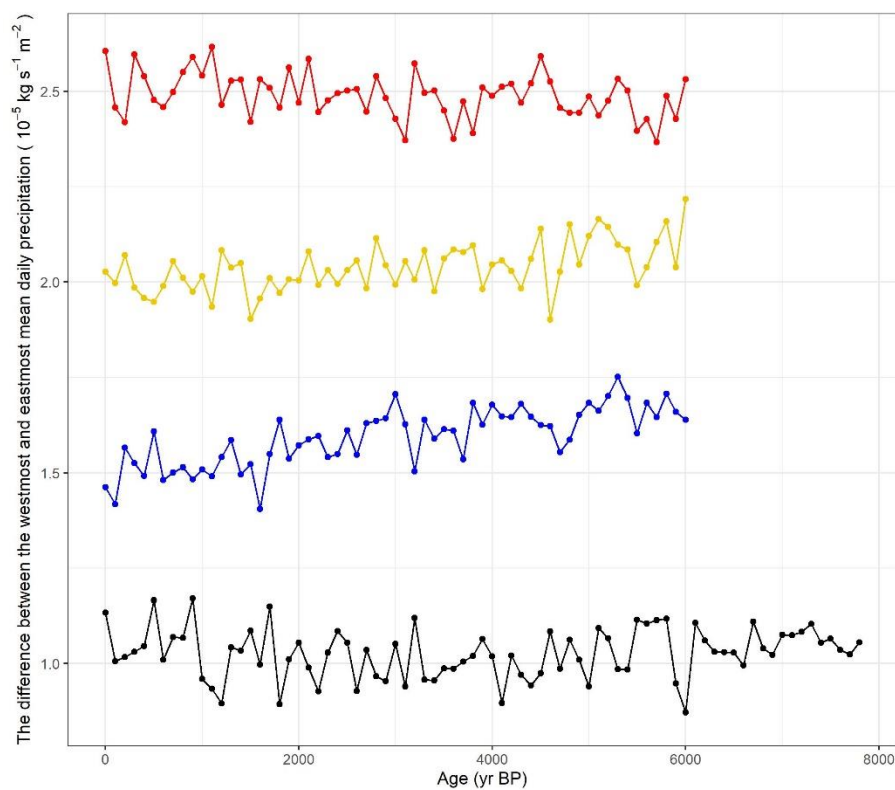
"The change in moisture gradient during the mid-Holocene, however, suggests an alternative explanation whereby changes in summer temperature are a response to land-surface feedbacks associated with changes in moisture. Specifically, the observed increased advection of moisture into eastern Iberia would have created wetter conditions there, which in turn would permit increased evapotranspiration, implying less allocation of available net radiation to sensible heating, and resulting in cooler air temperatures."

13. line 222 'Stronger moisture advection is not a feature of the transient climate model simulations, which may explain why these simulations do not show a strong modification of the insolation-driven changes in summer temperature. The failure of the current generation of climate models to simulate the observed strengthening of moisture transport into Europe and Eurasia during the mid-Holocene has been noted by other studies (e.g. Bartlein et al., 2017; Mauri et al., 2014)' The first sentence is confusing in view of Figure S9. The models do show temperature evolution through time. I think the authors mean that the models are not able to counteract or shield the insolation forcing. Also, is this conclusion (moisture advection) derived by other studies (then please cite references) or did the authors look into the

simulated moisture advection or is this conclusion reached by indirect reasoning? Please, be here as clear as possible.

The transient simulations do not show an increase in moisture advection during the mid-Holocene and the changes in summer temperature follow the changes in insolation. Our argument is therefore that this is why they are not consistent with our reconstructions. The Bartlein et al and Mauri et al papers both showed that the models do not advect sufficient moisture into Europe and Eurasia, but both focused on time-slice 6 ka simulations. Figure S9 only shows the regionally averaged changes in precipitation in the transient simulations and we agree that our point would be made more clearly if we showed the changes in the west-east gradient. We have now included such a plot in the Supplementary (Fig. S10).

Fig S10. The difference between the westmost and eastmost simulated mean daily precipitation in Iberian Peninsula between 8 ka and 0 ka, smoothed using 100 year bins. Here BP means before 1950 AD. The black lines represent Max Planck Institute Earth System Model (MPI) simulations, the red lines represent Alfred Wagner Institute Earth System Model (AWI) simulations, the blue lines represent Institut Pierre Simon Laplace Climate Model (IPSL-CM5) TR5AS simulations, the orange lines represent Institut Pierre Simon Laplace Climate Model (IPSL-CM6) TR6AV simulations.



We have modified the text for clarification, as follows:

Stronger moisture advection is not a feature of the transient climate model simulations, which may explain why these simulations do not show a strong modification of the insolation-driven changes in summer temperature. The failure of the current generation of climate models to simulate the observed strengthening of moisture transport into Europe and Eurasia during the mid-Holocene has been noted by other studies (e.g. Bartlein et al., 2017; Mauri et

al., 2014) and is shown in Fig. S10. This data-model mismatch highlights the need for better modelling of land-surface feedbacks on atmospheric circulation and moisture.

14. Conclusion sections. The usual conclusion section is missing. This is to some extent a matter of style (or editorial guideline), but I find useful that a manuscript finishes off with a few bullet-point style list of most important take-home messages

We have added a concluding statement, as follows:

"We have used a pollen data set representing 117 sites across the Iberian Peninsula to make quantitative reconstructions of summer and winter temperature and an index of annual moisture through the Holocene. We show that the trends in winter temperature broadly follow the changes orbital forcing. Summer temperatures, however, do not follow the changes in orbital forcing but appear to be influenced by land-surface feedbacks associated with changes in the west-east gradient in moisture, which was considerably less pronounced during the mid-Holocene (8-4 ka)."

15. Fig S9. The reader will benefit from a reference to the model runs. I guess that the authors are using the runs described in Braconnot et al. (2019; doi:10.5194/cp-15-997-2019) and Bader et al. (2020; doi:10.1038/s41467-020-18478-6), but please, spell the names of the models in full, e.g. MPI-ESM-P, and give references to the runs used and shown in this figure. Also, some additional information could be useful for the reader as well, such as the spatial resolution. Also, the time axis is not clear enough: years BP?

We realise that we did not provide sufficient information about the transient simulations, and we have added text in the Supplementary to describe these simulations (and have referenced this in the main text), as follows:

#### Transient climate model simulations

We compared our reconstructions to outputs from four transient climate model simulations run as part of the PACMEDY project (<https://pacmedy.lsce.ipsl.fr/wiki/doku.php>), specifically two versions of the Institut Pierre Simon Laplace (IPSL) model, one with dynamic vegetation (IPSL-CM6, TR6AV) and one in which the dynamic vegetation was turned off (IPSL-CM5, TR5AS), version 2 of the Alfred Wagner Institute (AWI) Earth System Model (AWI-ESM2) and the Max Planck Institute Earth System Model (MPI-ESM). The four simulations were forced by evolving orbital parameters and greenhouse gas concentrations. The four models have different spatial resolution, with the finest resolution being  $1.875 \times 1.875^\circ$  (AWI, MPI) and the coarsest resolution being  $1.875 \times 3.75^\circ$  (IPSL-CM5). Results from these palaeo-simulations have been discussed in Braconnot et al. (2019a, 2019b); Carré et al. (2021); Dallmeyer et al. (2019).

Here are the references:

Braconnot, P., Crétat, J., Marti, O., Balkanski, Y., Caubel, A., Cozic, A., Foujols, M.-A. and Sanogo, S.: Impact of multiscale variability on last 6,000 years Indian and West African monsoon rain, *Geophys. Res. Lett.*, 46(23), 14021–14029, doi:<https://doi.org/10.1029/2019GL084797>, 2019a.

Braconnot, P., Zhu, D., Marti, O. and Servonnat, J.: Strengths and challenges for transient Mid- to Late Holocene simulations with dynamical vegetation, *Clim. Past*, 15(3), 997–1024, doi:10.5194/cp-15-997-2019, 2019b.

Carré, M., Braconnot, P., Elliot, M., d'Agostino, R., Schurer, A., Shi, X., Marti, O., Lohmann, G., Jungclaus, J., Cheddadi, R., Abdelkader di Carlo, I., Cardich, J., Ochoa, D., Salas Gismondi, R., Pérez, A., Romero, P. E., Turcq, B., Corrège, T. and Harrison, S. P.: High-resolution marine data and transient simulations support orbital forcing of ENSO amplitude since the mid-Holocene, *Quat. Sci. Rev.*, 268, 107125, doi:https://doi.org/10.1016/j.quascirev.2021.107125, 2021.

Dallmeyer, A., Claussen, M., Lorenz, S. J. and Shanahan, T.: The end of the African humid period as seen by a transient comprehensive Earth system model simulation of the last 8000 years, , doi:10.5194/cp-2019-86, 2019.

We have also modified the time axis to "(yr BP)" and modified the caption of the Supplementary Figure to make it clear which models we have used, as follows:

" Simulated mean values of mean temperature of the coldest month (MTCO), mean temperature of the warmest month (MTWA) and mean daily precipitation in Iberian Peninsula between 8 ka and 0 ka, smoothed using 100 year bins. Here BP means before 1950 AD. The black lines represent Max Planck Institute Earth System Model (MPI) simulations, the red lines represent Alfred Wagner Institute Earth System Model (AWI) simulations, the blue lines represent Institut Pierre Simon Laplace Climate Model (IPSL-CM5) TR5AS simulations, the orange lines represent Institut Pierre Simon Laplace Climate Model (IPSL-CM6) TR6AV simulations."