Author response to Reviewer #2

On the manuscript

Mid-Pliocene West African Monsoon Rainfall as simulated in the PlioMIP2 ensemble

by Ellen Berntell et al., submitted to *Climate of the Past* (https://doi.org/10.5194/cp-2021-16).

We thank the reviewer for their valuable comments and the time and effort spent reviewing our manuscript. Below are listed our response to the comments, with the reviewer's comments in black and our replies in blue.

Reviewer Comment #1: The authors conclude that the strengthened mid-Pliocene WAM is "most likely due to the greenhouse gas forcing". I am not entirely convinced by this main conclusion. Given the large spread in projected future WAM changes in the CMIP3 and CMIP5 ensembles, GHG forcing does not seem very likely as the (only) major cause for the very consistent and robust rainfall changes in the PlioMIP2 ensemble. Instead, I presume that other factors also play a crucial role. In particular, I suspect that the prescribed Pliocene vegetation cover over North Africa plays a key role, which would probably imply circular reasoning when the authors state that Pliocene greening of North Africa indicates wetter conditions, "which is qualitatively consistent with the results from the PlioMIP2 ensemble". I think the authors should provide some stronger arguments to conclude that GHG forcing is the major driver for the stronger mid-Pliocene WAM. I also wonder about the roles of other Pliocene boundary conditions that were applied in these simulations, like lake fraction, soils, a reduced Greenland ice sheet and the land-sea mask (Haywood et al., 2016). Unless sensitivity studies with individual forcings (i.e. boundary condition changes) can be presented, I suggest to perform some more detailed analyzes. For instance, how much do surface albedoes change (see Charney feedback through vegetation-induced albedo changes)? How large is the contribution of local water recycling (e.g. Brubaker et al., 1993)? What about changes in the large-scale meridional temperature gradient, which could be affected by reduced ice sheets and a stronger AMOC, which in turn could be induced by the closing of Bering Strait? A strong AMOC and a warm North Atlantic are well known key drivers of a stronger WAM (e.g. Mulitza et al., 2008). Maybe a combination of different forcing factors can explain the robust wettening of Pliocene North Africa, but I doubt that it is only the effect of GHG.

Response: We thank the reviewer for this comment, and agree that indeed GHGs are not solely responsible for the precipitation changes. Vegetation and land-surface changes are known to impact the West African Monsoon and rainfall through, e.g., vegetation-albedo feedbacks (Charney et al., 1975), and North Atlantic sea surface temperatures have long been linked to precipitation changes in the Sahel and West African region, suggesting that non-CO_2 boundary conditions play an important role in the mid-Pliocene precipitation response over West Africa. A recent paper by Zhang et al. (2020) has indeed shown a stronger AMOC within the PlioMIP2 ensemble for all models that include closed Arctic gateways. However, HadGEM3, which did not include this enhanced land/sea mask and instead exhibited a weakening of the AMOC still exhibit a precipitation increase over West Africa close (within 1 std) to the ensemble mean, suggesting that, in this case, other boundary conditions (such as vegetation) might play a larger role in the mid-Pliocene precipitation changes over West Africa. The results from different PlioMIP2 sensitivity experiments for many of the different ensemble members have now been published, and we will expand the discussion on the role of the different non-CO2 boundary conditions (e.g., vegetation, topography) and the changes they induce (e.g., changes to AMOC) on the enhanced monsoonal rainfall in the revised manuscript.

Reviewer Comment #2: Please discuss whether the rainfall increases are sufficient to maintain the prescribed Pliocene vegetation cover. If the simulated rainfall increase was too small, the authors should tone down their statement that the PlioMIP2 "results are consistent with geological evidence".

Response: Thank you for this suggestion. Comparing the vegetation pattern in the COSMOS model (which includes dynamic vegetation and whose precipitation response over West Africa is close to the ensemble mean) to the reconstructed vegetation cover in PRISM4 (used as boundary conditions in PlioMIP2) can give an indication on if the modelled climate is in agreement with the reconstructed climate and if the precipitation changes are sufficient to sustain the prescribed vegetation cover. The vegetation pattern in COSMOS is generally in agreement with the expected vegetation patterns during the mid-Pliocene (Stepanek et al., 2020), and we will discuss this further in the revised version of the manuscript.

Reviewer Comment #3: Regarding WAM dynamics the authors only show SLP and 850h Pa wind anomalies. Other key dynamical features of the WAM, like the AEJ and TEJ are not considered at all, but are known to impact West African summer rainfall. At least a latitudinal transect of mean summer zonal wind over Africa, similar to figure 5 in Nicholson (2013), should be presented to provide a wider picture of the changes in the WAM system.

Response: We agree with the reviewer that these key dynamical features are important when it comes to understanding changes to the West African Monsoon. However, the aim of this paper is to evaluate changes to the precipitation, and we believe that a detailed dynamical analysis is outside the scope of this manuscript which focuses on the large-scale patterns of the rainfall within a large ensemble. A more dynamically oriented study is surly worth doing, and we plan to explore this in a future paper using a more limited number of models.

Reviewer Comment #4: Line 280: What is the main reason for the stronger rainfall changes in PlioMIP2 compared to PlioMIP1? Is it a change in the boundary conditions or perhaps improvements in the climate models? Please discuss.

Response: We thank the reviewer for this comment, it is indeed an important question although one that is difficult to answer with the simulations available within PlioMIP2. Some of the larger changes to the boundary conditions in PlioMIP2 compared to PlioMIP1 is the land/sea mask, but the precipitation response over West Africa in HadGEM3, which did not include this boundary condition, still remains close (within 1 std) to the ensemble mean. Generally, models that exhibit a large temperature sensitivity to the PlioMIP2 forcing and boundary conditions also exhibit a large precipitation response, and within model families later model versions tend to be more sensitive than earlier version (Haywood et al., 2020), indicating that the strength of the increased rainfall changes is more related to model sensitivity and the model improvements that have been done between PlioMIP1 and PlioMIP2. We will address this further in the revised manuscript.