Author response to Reviewer #1

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 and constructive comments and the time and effort spent reviewing our manuscript. Below is listed our response to both the general and specific questions, with the reviewer's comments in black and our replies in blue.

Reviewer Comment #1: The main explanation for the increase in monsoon precipitation is seen in the increased atmospheric CO2 level in this study. However, the modern atmospheric CO2 content is at the same level and observations show a precipitation band in North Africa that does not extend very far north and also nowhere near as high precipitation rates as shown in this study for the mid-Pliocene. The question therefore arises as to what extent other causes might be (at least partly) responsible for the area-wide increase in precipitation. It would be helpful to introduce and discuss other boundary conditions that may affect the monsoon rainfall. Land surface changes are only briefly addressed. These certainly contribute to an increase in precipitation, but are there other factors? In this context, I would suggest showing a map with the prescribed vegetation pattern and maybe also a map for the vegetation anomaly simulated by COSMOS. And I recommend to discuss the vegetation influence in more detail.

Response: Thank you for this comment. We agree with the reviewer that the higher atmospheric CO2 concentration is indeed not the only boundary condition affecting the precipitation in North Africa during the Pliocene. Vegetation/land surface changes are known to impact the precipitation, and we will expand our discussion on the role of non-CO2 forcing (vegetation, topography). As per your suggestion, we will include a map of the prescribed mid-Pliocene vegetation and discuss it in relation to the precipitation changes as well as the vegetation patterns simulated by the dynamic vegetation model COSMOS.

Reviewer Comment #2: Some parts of Africa receive significantly high amounts of precipitation during June and also during October and some of the models simulate a strongly increased precipitation at mid-Pliocene during October. I understand that, with respect to the analysis of the monsoon flow etc., the core summer monsoon season is taken for the calculation of the mean distributions. But, I think the prolongation of the monsoon season is one of the most interesting aspects in the results. Therefore, I recommend to either include both month (or at least October) into the mean, or (if the atmospheric dynamic is significantly different between October and JAS) to present and discuss additionally a plot on the October precipitation and atmospheric circulation.

Response: Thank you for this suggestion. Both the precipitation response and the atmospheric dynamics are very similar for JAS and October, and given that these are the four months that exhibit the largest precipitation anomalies in Sahel we will as per your suggestion include October into the seasonal mean.

Specific comments:

Reviewer Comment #3: L73: model studies or reconstructions?

Response: Thank you for pointing this out, the text has been clarified to indicate that the reference refers to model studies.

Reviewer Comment #4: Fig.1: The different colours are not easy to distinguish, maybe you can think about using different line types for similar colours. In the right panel, the line for the observation cannot be seen, it would help to plot the MMM and modern line on Top of the others.

Response: The line styles and colours in Fig. 1 have been altered to make it easier to distinguish between the different models, and the MMM and Modern lines have been shifted to be on top of the lines for the individual models.

Reviewer Comment #5: Fig.1: One of the most interesting question is the WAM progression into the Sahara Desert. Please think about including also a seasonal cycle plot for the Sahara (e.g., 20°N-30°N, 20-30°E).

Response: Thank you for this suggestion, we have added the seasonal cycle for the Sahara region to Fig. 1.

Reviewer Comment #6: Fig.1: In the modern precipitation distribution, the isohyets are tilted, i.e., on the same latitude, rainfall is higher in the western part than in the eastern part of North Africa. Due to this, the region used for analysing the seasonal cycle is often limited to 10°W-10°E.

Response: Thank you for pointing this out. Indeed, the isohyets over West Africa are tilted in the modern climate which might motivate a more limited region. However, when comparing the seasonal cycles (pre-Industrial ensemble means shown below) we can see that they are virtually identical for the two cases (10°W-10°E vs. 20°W-30°E). The magnitude of rainfall is slightly higher with the smaller region, but the seasonal distribution is the same. Considering the models have different horizontal resolution we also prefer to use a larger region.

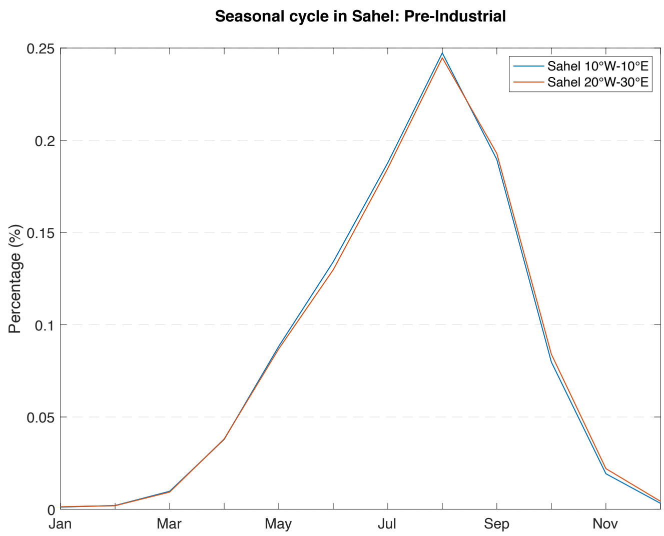

Fig 1. Seasonal cycle of precipitation in Sahel, Pre-Industrial ensemble means, averaged for a small region (blue) and a bit larger region (orange)

Reviewer Comment #7: L129: I'm not sure about the quality of the CRU TS v4 data for the early period (1901-1930), because weather stations and the data coverage was and is still very rare in this region. Maybe you can check if there are large differences to the 1960-1990 period, and if you can see interpolation residues.

Response: We agree with the reviewer, there is indeed a lack of spatial coverage in precipitation observations over West Africa for the earlier part of the 20th century. However, there are no large differences in the seasonal cycle between the 1901-1930 and 1961-1990 periods. The later period has slightly lower levels of rainfall in the monsoon season (approx. 0.5 mm/day difference in August), but remains above the PI ensemble mean.

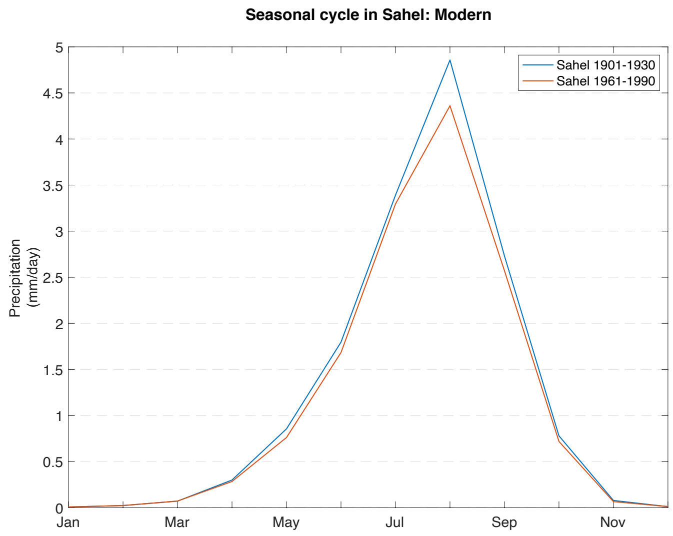

Fig 2. Seasonal cycle of precipitation in Sahel, 1901-1930 mean (blue) and 1961-1990 mean (orange) based on CRU TS v.4 data.

Reviewer Comment #8: L143-151: For better comparison, you could mention the observed PI rainfall rate.

Response: Thank you for pointing this out, we will include a comparison to the observed PI rainfall.

Reviewer Comment #9: Fig.2: The colours of the colour-bar are difficult to distinguish and it is not entirely clear which colour stands for which value. The pattern correlation value is very small. You could save space in the panel plots by omitting the coordinates in the individual plots. The land sea mask can be used for orientation and the coordinates can also be estimated from the MMM plot. This would make it possible to enlarge the plots without increasing the size of the overall plot.

Response: Thank you, we will enlarge the individual plots and make the information contained more easily distinguishable as per your suggestions.

Reviewer Comment #10: Fig.2: I think it would be interesting to discuss and analyse in more detail, why some models produce a very strong increase in rainfall and some do not. Is there a relationship to the prescribed boundary conditions or specific model physics? Is it just the sensitivity?

Response: This is indeed an interesting question. However, there is still a lot of uncertainty as to why the response differs within the model ensemble. Most models implement the same boundary conditions (although with slight differences due to, e.g., model resolution), and the models that have not used all the prescribed PlioMIP2 boundary conditions (HadGEM3 and COSMOS) still exhibit a precipitation response over West Africa within 1 standard deviation of the ensemble mean. Haywood et al. (2020) instead hypothesizes that the sensitivity to the Pliocene boundary conditions is mostly related to model parameterisation and initial conditions, and that within model families later model versions (with the same boundary and initial conditions) tend to be more sensitive than earlier version. The precipitation response over West Africa of the models is in many ways similar to their global response, e.g., GISS-E2-1-G exhibits the lowest precipitation sensitivity to the forcing both globally and over West Africa. We will expand the discussion on this further in the revised version of the manuscript.

Reviewer Comment #11: L159: WAM instead of WAS?

Response: Corrected.

Reviewer Comment #12: Fig.3: Please define the region "Sahel" again in the caption of the plot so that you can read the plot without reading the other figure captions or the text.

Response: Thank you for the suggestion, the region has been defined in the caption.

Reviewer Comment #13: L226: the word 'anomalies' is doubled.

Response: Corrected.

Reviewer Comment #14: Sec. 4.2: I think the pattern correlation for the modern precipitation distribution is not the best way to prove and summarize model performances, because North Africa has a very zonal and uniform precipitation pattern. Are there any climatic reconstructions that could be used to estimate whether the precipitation distribution calculated for MMM is correct and the increase in precipitation is of the right order of magnitude?

Response: Unfortunately, there are no direct precipitation reconstructions over West Africa for the mPWP. The available proxies are more to be used as qualitative or semi-quantitative indicators of mPWP hydroclimate (i.e., wetter, drier), and only a few of these records exist on or around North Africa. This was looked into recently by Ran Feng et al. (manuscript submitted to Sci. Adv.) and we will link more closely to her results in the revised version. However, comparing the vegetation pattern in the COSMOS model (which includes dynamic vegetation and whose precipitation response 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 we will expand on this in the revised version of the manuscript.

Reviewer Comment #15: L.327: "...our results support a future strengthening of the WAM and rainfall increase over West Africa and Sahel in a high CO2 scenario." I think that it is not necessarily possible to conclude from the analyses for the mid-Pliocene warm period how the WAM will change in the future. The future will experience much higher CO2 levels and it is not guaranteed that this will lead to a permanent expansion of vegetation. This depends on very different factors.

Response: Thank you for this comment. We agree with the reviewer that many different factors might impact the future of the precipitation in West Africa, especially the future changes to the vegetation, and we will revise the manuscript to reflect this.