Response to Reviewer 1

We are very grateful to The Reviewer for taking their time to review our manuscript. Their supportive comments and suggestions have enabled us to further improve the clarity of our manuscript.
The original comments from the reviewer are displayed in highlighted blocks, and below them are our responses to each of the comments.

Comment 1.
General

This paper addresses the topic of MH orbitally forced climate and environmental transitions and associated land cover feedback in the MENA region. The topic is relevant for the understanding of climate dynamics at global and regional scales, in the context of ongoing climate change which requires urgent adaptation measures.

Although the overall methodology used to investigate the topic is appropriate, the paper fails in meeting the standards for publication in CP. My main concerns are listed below:

- The paper is very long and not very well organised, with many figures composed by many panels, making difficult to establish the connection between the research questions, the methodology and the results. Material should be selected to only present what is relevant to the conclusions. The use of English needs further improvement.
- The research questions are not clearly outlined.
- The experimental setup seems very complex and the relationship with the research questions is not clear.
- Differences and comparisons are presented without any assessment of statistical significance, and the evaluation of whether the results are quantitatively meaningful is not possible.
- The discussion of the physical processes is often speculative only, not supported by evidence.
- The novelty of the results is questionable: the importance of the land cover processes for correctly simulating MH climate in the MENA region has been already pointed out in many modelling studies: what is the added value of this paper? In particular, what do we learn from the analysis regarding the optimisation of the parametrisation schemes to simulate MH climate in the MENA region?

For the above reasons, I cannot recommend the publication of this paper, which I believe still requires substantial and major modifications. I add below some comments that I hope can be helpful to the authors for improving the paper.

Regarding the critical issue raised in the second point of the reviewer's general comment, we understand on the basis of the comments from reviewer 1 that the reviewer has experienced significant difficulty in understanding the primary issue, which it is our purpose to address in this manuscript. In order to make absolutely clear what our purpose is in this work, we have produced a new figure, shown at the end of this document as an aid in providing the needed clarification. This figure will be included in the revision of the paper we are preparing. It shows in part a (redrawn from deMenocal et al. (2000)) dated demonstrating that the the most recent GS period began at 14.5ka and ended at approximately 5.5ka. In part b of this figure (redrawn from Roberts et al. (2011)) we provide the palynological information demonstrating that the end of the Green Sahara period was accompanied by a marked change in the land cover of the Levant, from one of forests to one of grasslands. Our purpose in this paper is to demonstrate that this is not a chance correlation, but rather associated with causation in that the end of Green Sahara conditions directly lead to a drop in annually averaged precipitation over the Levant that was sufficiently strong as to eliminate the forest cover from this region. This is a critical issue as in the archaeological literature, it has often been assumed that this change in land cover was caused anthropogenically by forest clearance required for the onset of farming (Klein Goldewijk et al., 2017, Roberts et al., 2019, 2011).

Given all issues addressed by reviewer 1, we propose a major revision of our manuscript that includes the following changes:

- A full revision of the introduction section so the research question described above is fully addressed.
- We will include modifications in the experiment design section to clarify the experiment design and highlight the purpose of each experiment we perform.
- The results section will be reorganized so that it focuses on analyzing experiment results connected to the focus of our manuscript. We will also include further analysis that directly address the issue of statistical significance of the results obtained.
- We will move the detailed analysis on the behavior of the land surface scheme ensemble to supporting materials, as it is not directly important to the main focus of our manuscript, but is important supporting material. This move will significantly shorten the length of our paper.
- Further efforts will be invested in improving the quality of the English of the article.

We hope that our revised manuscript will satisfy the requirements for publication in Climate of the Past.

Specific

Comment 2.
Title: Where in the paper re-desertification is discussed? The paper is about greening.

The time period of 6ka BP is at the end of the most recent GS period, instead of its start. Therefore the natural climate evolution in northern Africa was from green state to non-green state, thus re-desertification instead of greening.

Comment 3.
Introduction cites the relevant literature and sets the background for the study. However, research questions and objectives of the paper are not declared. I suggest you add at the end of the introduction a statement regarding research questions and objectives of the paper.

The introductory materials provided in response to reviewer 1 presents precisely the new material which will be explicitly included in our revision of the manuscript.

Comment 4.
Section 2.1: A table summarising the experimental setup would be helpful to visualise the overall experimental approach. Please also clarify what you mean with "sensitivity expansion simulations".

We will include the suggested table in the revised manuscript, and modify the experiment design section to clearly define the sensitivity experiments we have performed.

Comment 5.
Section 2.2: The experimental setup is rather complex, description needs improvement. Please clarify that each combination of parametrisation schemes represents an ensemble member (the expression "each ensemble set" at L151 is confusing). Please also explain the rationale behind the definition of the different ensembles and members. Finally, please better clarify the objective of the albedo experiment.

The design of the analysis we have performed is intended to demonstrate the range of impacts on the decrease in precipitation over the ancient Near East that is associated with the end of the northern Africa GS conditions. We employ the WRF based downscaling pipeline to explore the range of impacts expected due to the choice of different physics parameterization schemes that we can enable in WRF, as this model is explicitly equipped with an extremely wide range of physics parameterizations. By varying the sets of physics parameterizations in the model, or modify the prescribed albedo field, we are able to assess the robustness of our conclusion that the end of GS conditions over northern Africa leads to a marked reduction in precipitation over the ancient near East. The ensemble of results we report provide the needed evidence. This information will be explicitly added to the experiment design section of the revised manuscript.

Comment 6.
Figures 2 to 6: Why N individual members are not shown? On which longitudinal band precipitation is averaged? How statistical significance of the anomalies is estimated? How proxy-model agreement is assessed? Specifically, how uncertainty in proxy reconstructions compare with the internal variability of model simulations?

The individual N members were analyzed in the previous study, namely Xie et al. (2025). It was found in that study that there was no significant difference between the ensemble average and each of its members in terms of changes in precipitation and near surface temperature, with and without a prescribed GS surface, therefore we think that showing the N ensemble average would be enough in representing N ensemble simulations. Instead We could add individual N members into these figures, but we prefer not doing so as the reviewer already mentioned that there are too many sub-figures in our manuscript. The average of precipitation is computed over the range of longitudes shown by the labels of the x-axis in the respective subfigures. In the revised manuscript, we will add an explicit analysis of the statistical significance on the anomalies in both model simulations and proxy reconstructions.

Comment 7.
Section 3.3: This section should be reorganised to discuss the physical variables presented in Figures 9-13 along with the summer precipitation response presented in Figure 8. This would help the reader to better visualise the physical processes leading to the precipitation response.

In fact, in service to the reduction of length of the manuscript, we have decided to move significant detail on the impact of different ensembles into the supporting materials. Discussion on these results will be reorganized so the connection between fields presented in Figures 9-13 and the summer precipitation responses presented in Figure 8 is clearly addressed.

Comment 8.
Section 3.4: It is not clear why the albedo experiment is only briefly discussed in relation to the Middle East case study. The paper is already very long, and the discussion of the Middle East case seems to deviate from the main story. This is a very relevant topic indeed, and it would deserve a full article, instead of only such a brief discussion.

As mentioned in our response to the main comment, discussion of the variability of precipitation over the Middle East is the main target of our manuscript. When this variability is associated with the end of the GS condition over northern Africa, the critical issue in this regard concerns the accuracy of the availiable description of GS conditions. The best available model of these conditions, discussed in Chandan and Peltier, has to be considered an approximation. Our goal in adding the sensitivity experiment, which postulates an increase in albedo over northern Africa, is intended as a measure of impact of this uncertainty on the drop of precipitation over the ancient Near East due to the termination of the African Humid Period. We consider this to be an important contribution to the present manuscript, as it does assess the robustness of the precipitation drop required to explain the transition from forest landscape to a grassland landscape.

Minor/Technical

Comment 9.
L50: I'd also mention Africa-CORDEX.

L61: Can you please add some words about the specificity this experimental setup with respect to the CORDEX protocol?

We will add more discussion regarding the CORDEX protocol, including a reference to Africa-CORDEX, and a brief discussion that our experimental setup is built upon the Mid-Holocene forcing data available and is therefore different from the CORDEX protocol.

Comment 10.
Figure 1: A legend for the colours associated with the different land covers would be helpful. What do you mean by "in each region"? "Categories" instead of "category".

The full legend for the 24-category land covers used by WRF is available on the WRF website. Considering that the length of the manuscript is already long, we would prefer to add a reference to it instead of displaying it in full. We will revise "in each region" to "in the four regions that have a prescribed green surface" to clarify our setup.

Comment 11.

L203: Do changes in temperature and precipitation refer to the whole domain or to specific regions?

These changes in temperature and precipitation refer to the region where land surface conditions are changed to Green Sahara conditions. We will add this information in the revised manuscript.

Comment 12.
L206: I'm not sure 100% that you can use Mesopotamia to refer to modern Middle East: https://www.britannica.com/place/Mesopotamia-historical-region-Asia

We will change this term to the Middle East in the revised manuscript.

Comment 13.
L207: What L5 member are you referring to?

L5 member refers to a physics parameterization set used in the modern validation experiment, which is described in the referenced study. This physics set is not used in the current experiment.

Comment 14.
L226, 262, 294, 298, 337, 368, 540, 554: How statistical significance is assessed?
L267: Where exactly is the increase in precipitation observed?
L300: Where can we see the effect of increased evaporation on precipitation?

In the revised manuscript we will add more regional details in describing our results, and a quantitative analysis that addresses the statistical significance of the changes we observed.

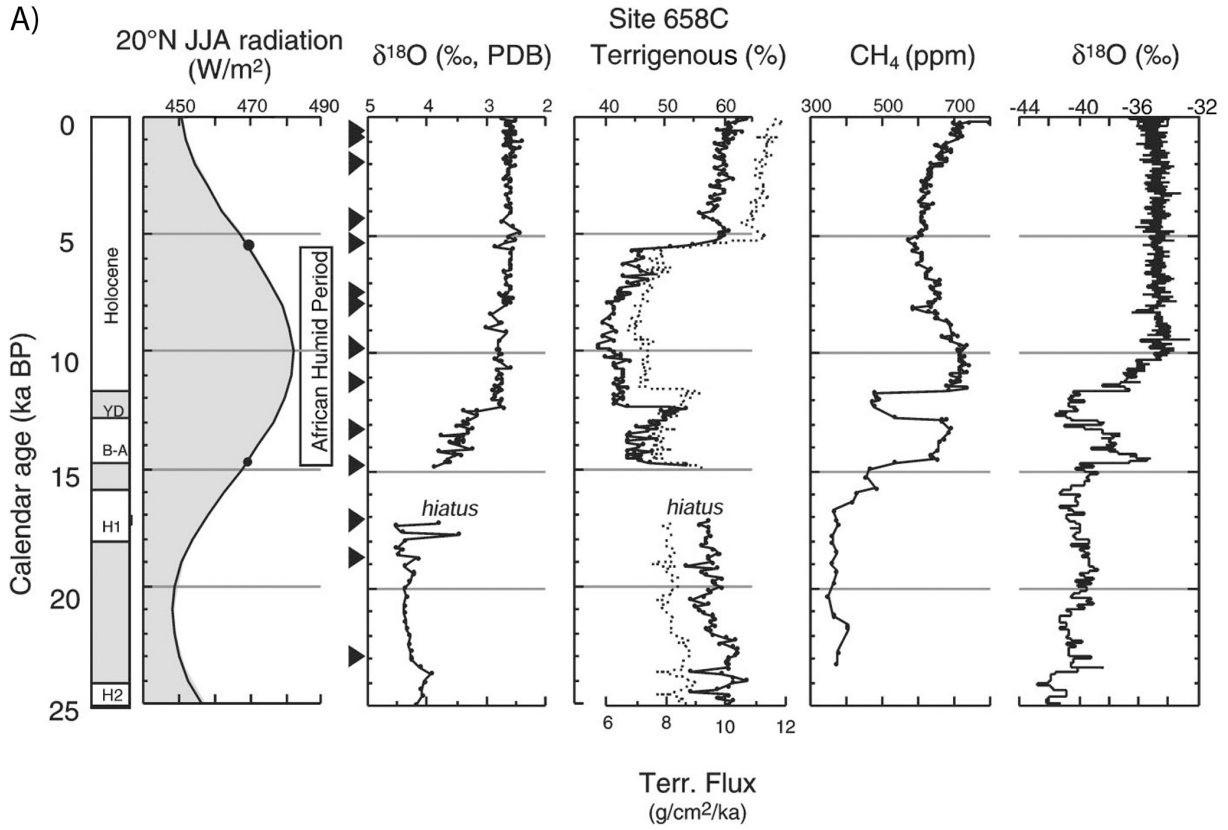
Comment 15.

L314-318: This part is speculative; we cannot see anywhere evidence of those processes going on.

Detailed information regarding these processes are provided in Section 3.3 of our manuscript, which provides the evidence. In the revised manuscript we will address the location of this discussion in this part.

Comment 16.
L44: Please check brackets. Same at L67, 176, 201, 204, 223, 224, 231, 241...
L110-113: This sentence is a bit intricated, please rephrase it.
L126: Please declare the variable name first and put the acronym in brackets.
L146-151: please check for typos in this sentence.
L166: I assume RCM should be GCM instead.
L169: Please use clear different labels for RCM and GCM simulations.
L178-186: The phrasing of this paragraph makes difficult to follow the story, please consider rephrasing and streamline it.

We appreciate the extend to which reviewer 1 has carefully considered all aspects of the written text. In the revision, we will pay special attention to each of these individual comments.


A)
20°N JJA radiation (W/m²)
δ18O (‰, PDB)
Site 658C
Terrigenous (%)
CH4 (ppm)
δ18O (‰)
Calendar age (ka BP)
Holocene
YD
B-A
H1
H2
African Humid Period
hiatus
hiatus
Terr. Flux (g/cm²/ka)

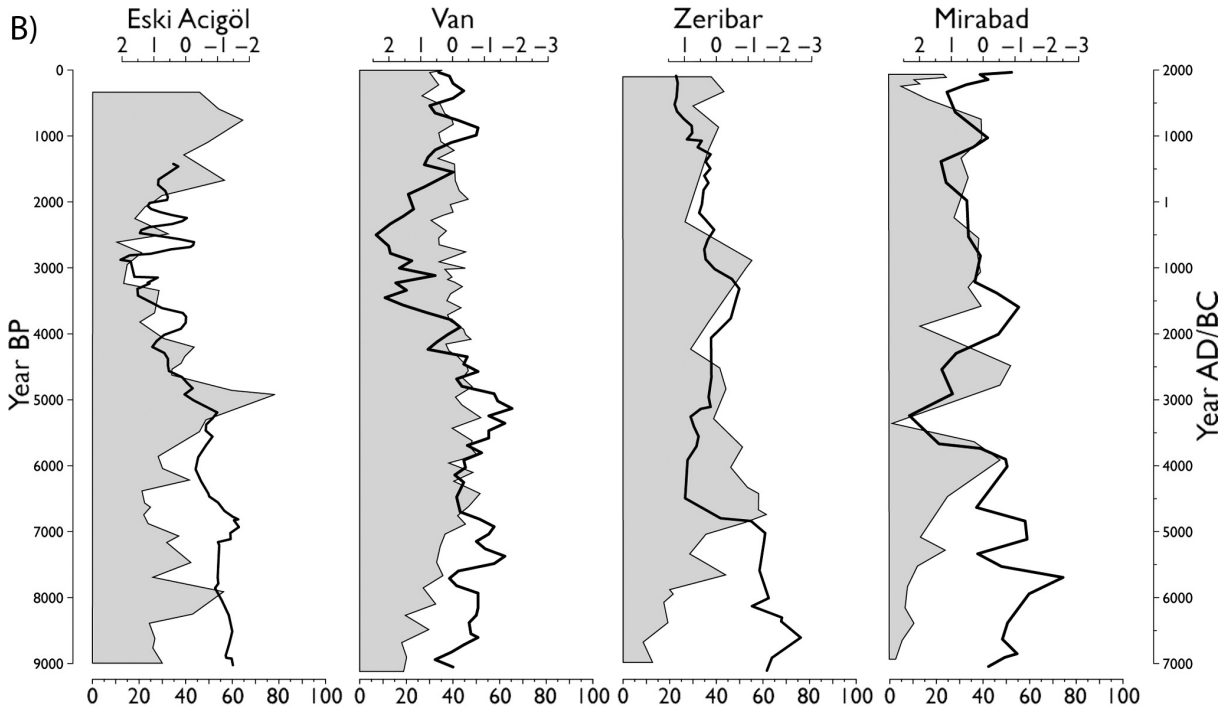

B)
Eski Acigöl
Van
Zeribar
Mirabad
Year BP
Year AD/BC

Figure 1: Part A of this figure shows a comparison between boreal summer (JJA) average insolation at 20° N Berger and Loutre (1991) with benthic isotope record and terrigenous percentage and flux records from a marine sediment record excavated off the coast of West Africa (20°45'N 18°35'W, deMenocal et al. (2000)), and with atmospheric methane concentration preserved in ice bubbles and oxygen isotope composition of glacial ice in the GISP2 Greenland ice core (Blunier et al., 1995, Dansgaard et al., 1993). Time range of this comparison covers 25k calender year BP. These records show the onset of the most recent African Humid Period occurred approximately around 14.5ka BP, during which increase of summer season insolation over northern hemisphere coincides with increase in terrigenous proxy percentage, increase in atmospheric methane concentration, and decrease in O18 isotope concentration. These changes in climate proxies suggest an increase of terrestrial vegetation production over northern Africa, an expansion of boreal wetlands, and an increase in global temperature at this time. The terrigenous percentage and flux records has a significant decrease near 5.5ka BP, marking the termination time of the most recent Africa Humid Period, which also coincides with a decrease in northern hemisphere summer season insolation. Part A of this figure is a redraw of Figure 4 in deMenocal et al. (2000). Part B of this figure shows delta O18 and Arboreal pollen percentile from four lake sediments records around the Middle East region, covering a time period of 9k calender year BP. These records shows a transition of climate trend near 6ka BP, separating a period of increase in precipitation and tree cover around these lakes before it, and decline in precipitation and tree cover after it. The exact time of this transition differs between each lake record due to their geographical position. Part B of this figure is a redraw of Figure 6 in Roberts et al. (2011).

References

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