Summary

The author analyse two mid-Holocene climate model simulations using EC-Earth. The first of these is a standard PMIP type setup and the second includes a reduction in Saharan dust along with a prescribed greening of the Sahara. The authors focus on mid-latitude climatic impacts and in particular the changes in weather regimes and the NAO. The authors also evaluate the simulations with proxy records for temperature and precipitation. They find significant but similar impacts on the NAO and WR independent of the greening, but the agreement with proxy records is worsened in all areas but one when the Sahara is greened.

We thank the reviewer for the time s/he spent in revising and commenting our manuscript, and for the insightful comments, which helped in improving the paper. We agree with the reviewer that the Saharan greening doesn't improve the agreement with proxies. However, we highlight that the impact of the Sahara greening is larger on NAO in winter (see the Kolmogorov-Smirnov test), and WR frequencies show larger changes in the Green Sahara experiment, with respect to the PMIP experiment.

Recommendation

My only main comment is that some of the key findings could be more clearly articulated in the abstract and the conclusions. I also have a few minor suggestions about clarity that are listed below. Otherwise, this is a valuable study and I look forward to seeing it published.

We agree with the reviewer that the key findings should be better presented in the abstract and more deeply discussed in the conclusions. Please find in the following our responses to your comments.

Main comments

A key finding here is that the MH_PMIP simulation performs better than the MH_GS in all regions but one according to the Cohen Kappa scoring. I think this needs to be clearly stated in the abstract.

We agree with the reviewer that this aspect should be mentioned in the abstract. A line has been added:

"Although the prescription of vegetation in the Sahara does not improve the proxy-model agreement, this study provides…"

This slightly surprising finding could also benefit from further discussion - at the moment the Conclusions seem to argue for more realistic mid-Holocene simulations, but clearly there are nuances here. What could be the cause of this? One question that came up on reading was whether the highly idealised nature of the GS simulation setup could play a role?

We believe that the proxy-model disagreement originates in part from some local inconsistencies of proxy reconstructions, often showing ambiguous regional features that are difficult to reconcile with the large-scale circulation patterns simulated by global climate models. However, we agree with the reviewer that the highly idealised nature of our simulation setup may contribute to these discrepancies. The experimental design, initially conceived to improve the proxy-model agreement specifically within the Sahara, was extended to explore potential remote impacts both in the Tropics (see Pausata et al. 2017a, b) and at mid-latitudes (this manuscript). We now highlight this aspect more clearly in the discussion of the proxy-model agreement in Section 5:

"Furthermore, it should be noted that the simulation setup is highly idealised, initially tailored to enhance the representation of the MH precipitation in the Sahara and to improve the regional proxy-model agreement. While this approach has yielded insights into specific climate impacts, such as those associated

with Sahara greening, the broader applicability to global mid-Holocene climate scenarios is limited. The improvement of the global proxy-model agreement would benefit from more refined MH climate modelling strategies, such as prescribing more realistic vegetation across latitudes and considering the seasonal vegetation cycle, which could better account for the nuanced large- and local-scale climate feedbacks that are critical for understanding past climates (see e.g., Swann et al., 2014)".

Minor Comments

In the discussion of mid-latitude temperature change it would be worth referring to Bartlein et al (2017) who looked at this issue in multiple models.

We thank the Reviewer for suggesting this reference that we missed. The paper is now referred in the Introduction.

Figures: There are a lot of figures here and the reader has to jump between the main text and the appendix figures quite a lot. Could you consider moving one or more of these figures into the main text to reduce this. At least figure A2 would be better in the main text.

Fig. A2 is now moved to the main text, as new Fig. 4.

Lines 45-47: "However, the interpretation of these climatic changes, particularly on temperature and precipitation patterns, as indicated by proxies, seem potentially inconsistent with the suggested changes in the atmospheric circulation (e.g., the positive-to-negative shift in the NAO/AO phase)."

The sentence is rather obscure indeed, it is now rephrased:

"(e.g., a drier eastern North America, warmer Scandinavia and colder Mediterranean would be inconsistent with a positive-to-negative shift in the NAO/AO phase)".

Line 231: "However, the difference in the NAOI distributions between the MHGS and MHPMIP experiments is less significant ($p<0.11$)".

Do you mean not significant or just less?

We set the threshold for significance at $p<0.05$, however there is a signal of shifting NAOI distribution between the MHGS and MHPMIP experiments. We changed "less" to "weakly".

Lines 232-237: "Circulation and surface anomaly patterns associated with the NAO positive phase in the MHPMIP (not shown) and the MHGS experiments (Fig. 7c, d) are very similar. …. In particular, the thermal and rainfall anomalies are more pronounced when Saharan greening is taken into account, due to the significant difference in the NAO phase shift with respect to the PI period."

These two statements seem contradictory to me. Please could you clarify?

Because of the shift of the NAO from a prevailing positive phase into prevailing negative, we expect to see temperature and precipitation anomalies associated with a negative NAO. Because we show that in MHGS the shift is more negative than in MHPMIP, those anomalies will be more pronounced in MHGS than in MHPMIP. However, because the differences in the NAO phase in MHGS and MHPMIP is only weakly significant, we replace "significant" with "larger".

Line 287: "… suggesting that the effect of the Saharan greening on the atmospheric circulation and the associated thermal and rainfall anomalies amplifies the changes driven solely by the orbital forcing"

Can you provide any potential explanations for this?

An analysis of the physical mechanisms responsible for the changes in the frequency of the atmospheric WRs in the different experiments is beyond the scope of this paper. However, in Section 5 we discuss a possible explanation of how enhanced deep convection in the Sahara adds on the orbital driven changes:

"The responses in temperature, precipitation and atmospheric dynamics are more pronounced in the MHGS simulation, indicating the significant influence of the Saharan greening on climate in the Northern Hemisphere. There is a broad literature on tropical-extratropical interactions triggered by tropical forcings such as the Indian monsoon and the El Niño/Southern Oscillation [e.g., Hoskins and Ambrizzi (1993); Rodwell and Hoskins (1996)]. More recently, the African monsoon has been indicated as a possible source of tropical-extratropical teleconnections (Gaetani et al., 2011; Nakanishi et al., 2021), reinforcing the hypothesis that the strengthening of deep convection in northern Africa associated with the Saharan greening could lead to climate impacts in the extratropics".

Lines 367-369: "This suggests that the MHGS simulation more effectively captures precipitation patterns compared to seasonal temperature patterns across the mid-latitudes"

Shouldn't this be MH_PMIP as the MH_GS runs has lower scores for every region except Asia?

This sentence refers to the comparison between model representation of precipitation and seasonal temperature anomalies in MHGS only, it is not a comparison with MHPMIP. A similar behaviour is also seen in MHPMIP.

Line 361: "numerous inconclusive MH proxy records"

Could you define what you mean by inconclusive?

We label as inconclusive those proxy records not providing a robust estimation of the change (or no change). See Section 2. A sentence has been added to the text:

"(as defined above, those record not providing a robust estimation of change or indicating no change)".

Line 405: "In addition, it is shown that the simulated Saharan greening drives"

Shouldn't this be the mid-Holocene orbit as the modes are similar in both GS and PMIP?

In Table 2 we show that, with respect to the MHPMP experiment, MHGS drives large changes in the frequency of occurrence of most of the WRs (NAO+, NAO-, SB in winter; NAO+, AR in summer). The spatial patterns do not change much among the three simulations, actually.

Line 409-410: "the changes driven by the Saharan greening in large-scale circulation indicate plausible explanations for the proxy evidence."

It's not clear what this really means but it sounds like its contradicting the Cohen's Kappa scores which show that the GS simulation is mostly worse than the PMIP simulation?

We agree that the Cohen's Kappa index shows improvements in only Asia in the MHGS simulation. However, we here highlight that regional inconsistencies in proxy reconstructions make difficult the link with large scale circulation patterns, with the exception of Asia, where proxy records show a more spatially homogeneous signal. Moreover, an overall more plausible association between precipitation

reconstructions and changes in the large-scale circulation is provided by the MHGS experiment. We rephrase for clarification:

"the changes driven by the Saharan greening in the large-scale circulation indicate plausible explanations for the proxy evidence, especially for precipitation".

Line 412-414: "Furthermore, this modelling exercise also highlights the need for more refined MH climate modelling, such as prescribing realistic vegetation across latitudes and considering the seasonal vegetation cycle, to account for large- and local-scale climate feedbacks."

These sound like sensible suggestions but they come slightly out of the blue here right at the end. Where do these ideas come from? Could you link them to your work or other studies in some way?

We rephrased this sentence in response to one of your main comments above:

"Furthermore, it should be noted that the simulation setup is highly idealised, initially tailored to enhance the representation of the MH precipitation in the Sahara and to improve the regional proxy-model agreement. While this approach has yielded insights into specific climate impacts, such as those associated with Sahara greening, the broader applicability to global mid-Holocene climate scenarios is limited. The improvement of the global proxy-model agreement would benefit from more refined MH climate modelling strategies, such as prescribing more realistic vegetation across latitudes and considering the seasonal vegetation cycle, which could better account for the nuanced large- and local-scale climate feedbacks that are critical for understanding past climates (see e.g., Swann et al., 2014)".

Technical Corrections

Hermann et al (2018) is missing from the reference list?

Added, thanks.

Figures 2 and 3: could you make the lines slightly less thick - as they are they overlap a bit too much.

Done.

Contributions: "QZ run the simulations" -> "QZ ran the simulations".

Corrected, thanks.