Response to Community Comment 1 (CC1) on: *"Threshold in orbital forcing for onset of African Humid Periods decreases with increasing greenhouse gases"* by Mateo Duque-Villegas et al.

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We thank Dr. Zhengyu Liu very much for carefully reading our manuscript and for providing constructive remarks. Below we respond to every comment (blue font, our response in black font).

[0] This paper discusses the simulation of the North Africa monsoon and vegetation in the last 190,000 years. In particular, it highlights that an increased GHG lowers the threshold for Africa Humid Period (AHP) in the vegetation coverage. The paper is interesting and should be published. But, the paper would be more interesting to readers if some points can be clarified before publication.

Major questions

[1] The first question is on the mechanism of this threshold change in the model. Why is the threshold reduced (instead of increased) at a higher CO2? Can some specific sensitivity experiment be performed to show this change of threshold is caused by some vegetation (model) property/threshold, changing at different levels of CO2?

Changes in orbital forcing and GHGs radiative forcing have an amplifying effect on the simulated climate. Hence, with higher GHGs levels the system responds earlier to smaller orbital forcing. This has been demonstrated by, for instance, sensitivity experiments in Claussen et al. (2003), who used the same model. They show how CO_2 and orbital forcings affect dynamic and thermodynamic contributions to Saharan precipitation. D'Agostino et al. (2019) also looked into these contributions in CMIP5 experiments and arrived at a similar outcome. Following Brovkin et al. (1997), we see that there is a minimum of Saharan vegetation (or precipitation) after which the precipitation–vegetation feedback sets in. With dynamic (circulation) effects alone, caused mainly by the changes in orbital parameters, the minimum triggering value of vegetation (or precipitation) is only reached when the insolation is strong enough (expressed in terms of a monsoon index - which will be changed, see below). However, when thermodynamical effects become stronger (increased GHGs, increased atmosphere warming, increased water vapour), the minimum value of vegetation (or precipitation) can be reached sooner or with a lower value of tropical insolation. Also see our response below to comment [4]. In a revised version of our manuscript we will update Line 361 to include a detailed explanation of this feedback mechanism, instead of only referring to previous studies.

[2] The second question is on the role of vegetation feedback. Does this model has a positive vegetation feedback on precipitation in N. Africa? Or What is the role of vegetation feedback here? It seems to me in Fig.3 that the threshold is present only for vegetation, not for precipitation. If vegetation has a strong positive feedback on precipitation, I would also expect a threshold appearing on precipitation.

Yes, the model has a positive vegetation feedback on precipitation in North Africa. This has been clearly demonstrated in Claussen et al. (2003). Figure 5 in this paper – which we reprint here for your convenience as Fig. C5 – shows sensitivity experiments with dynamic vegetation switched on (thick lines in Fig. C5b) and off (thin lines in Fig. C5b). From Fig. C5, one could compute the ratio of an increase in precipitation with vegetation dynamics switched on (ΔP(V)) and with vegetation

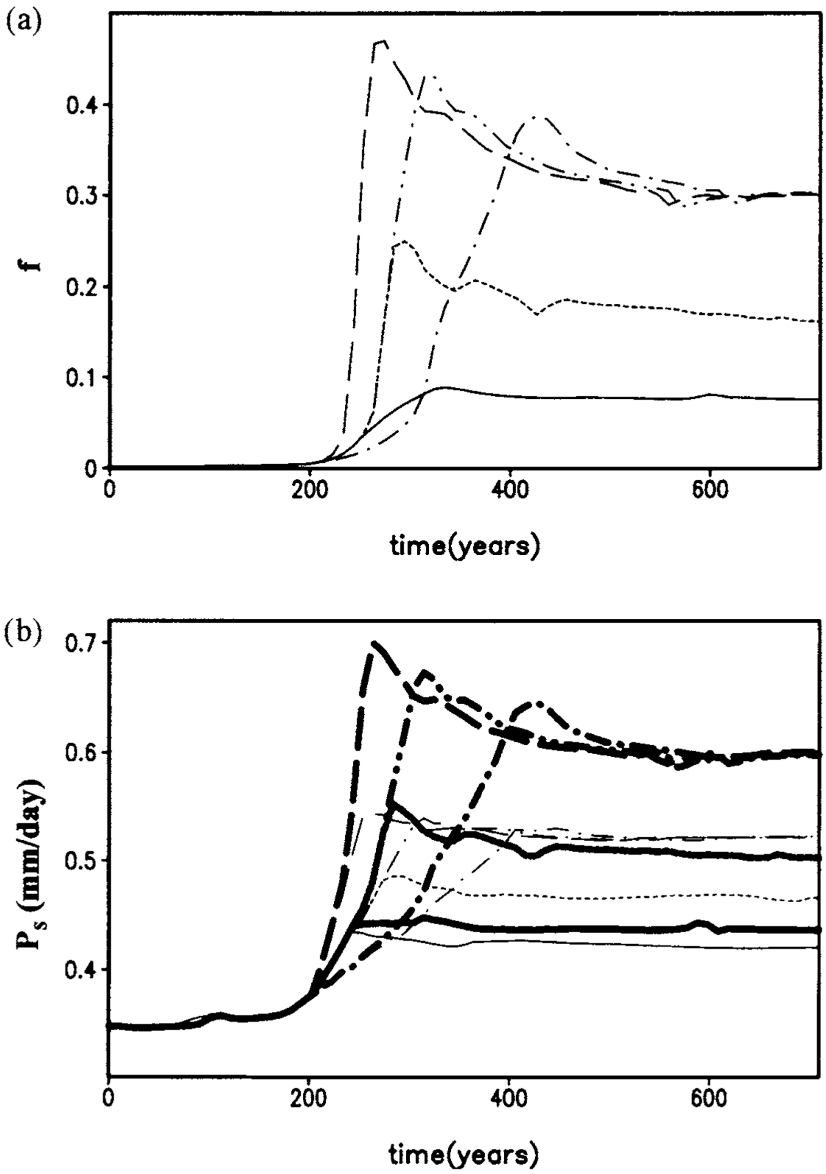

Figure C5: Reprinted from Claussen et al. (2003): Saharan vegetation fraction (a) and annual mean precipitation Ps (in mm/day) (b) as function of model years for different scenarios of changes in atmospheric CO_2 concentrations. The thin curves in (b) refer to results of the atmosphere-ocean-only model, the thick curves to results of the fully coupled model.

dynamics switched off (ΔP(0)), and one would arrive at a almost linear increase of Δ P(V) / Δ P(0) with vegetation fraction f.

Regarding the threshold behavior in precipitation, if one focuses on the summer (orange-yellow line) in Fig. 3a, a case could be made that the threshold also exists for precipitation, since there is a jump from 1 to 2 mm day^{-1}. In fact, if we lower a penalty parameter in the changepoint analysis function, a threshold can also be detected for precipitation. For simplicity, we focus only on the one abrupt change that seems the least sensitive to the changepoint method. In a revised version of our manuscript we will expand on Section 2.1 our description of VECODE – the dynamical vegetation component of the model. Also in Section 3.2 we will explain how the changepoint method did not find immediately an abrupt jump for precipitation.

[3] Related to this, the forcing factor separation shows a big difference between precipitation and vegetation, with orbital forcing dominant on vegetation, but not on precipitation.

We are afraid there is a misunderstanding, but we do not think Fig. 6 shows a big difference between vegetation and precipitation, since in both of them the orbital forcing is the dominating factor (both have a lot of pale blue). It is true there is a difference, which is related to the synergistic contributions (yellow and green) of GHGs and ice sheets with the orbital forcing. The difference could be explained by the fact that vegetation has an upper boundary at 100 %, and therefore the synergistic contributions cannot be as effective as in the precipitation response, since the orbital forcing alone already causes most of the changes to reach almost 100 %.

[4] It may be interesting to perform an experiment with the vegetation fixed to see how the precipitation changes. Even only one section of the simulations over 1-2 AHPs will be interesting.

We agree with the reviewer, and we will refer to the earlier CLIMBER-2 study by Claussen et al. (2003) as mentioned above.

Minor questions

[5] The definition of monsoon index is confusing to me. It itself sounds like an index for the monsoon response, but, it is really the insolation forcing. Perhaps, it should be changed to Monsoon Forcing Index.

We used term Monsoon Index as it was defined and used in the classical paper by **rossignol1983african**. But we agree with the reviewer and the review by Dr. Brierley (RC1) that for the readers' convenience, the term should be changed. In a revised version, we will refer to 'orbital forcing' or 'monsoon forcing index' as suggested.

[6] Why EI interglacial has a negative GHG of -2.8 W/m2? I thought interglacial has a higher CO2?

We are unable to find this in the text. In Table 1, EI experiments have 0.0 W m-2 as radiative forcing, since GHGs levels where close to an equivalent CO_2 concentration of 280 ppm.

[7] 3: Caption needs to be more specific. What is a dot for? Correlation thorough the entire period, or AHPs?

We agree with the reviewer that the caption needs to be expanded to briefly include the more detailed explanation given in the text (the dots refer to the values in Table 2).

[8] The title is on GHG lowers the threshold. But the paper discusses much beyond this, and actually, this point is somewhat lost in the discussion, at least, it does not read to me like the major point of the paper, because of so many other things discussed. Maybe this is indeed the most novel point, while other points are just consistency check...If that is the case, other parts can be simplified to highlight this novel point.

We agree with the reviewer that the title of our manuscript only refers to one highlight of our paper. We will ask the Editor, whether a change of title is possible. We think of "Effects of orbital forcing, greenhouse gases and ice sheets on Saharan greening in past and future multi-millennia" as a broader title.

References

Brovkin, V., Ganopolski, A., & Svirezhev, Y. (1997). A continuous climate-vegetation classification for use in climate-biosphere studies. *Ecological Modelling*, *101*(2–3), 251–261.

Claussen, M., Brovkin, V., Ganopolski, A., Kubatzki, C., & Petoukhov, V. (2003). Climate change in northern Africa: The past is not the future. *Climatic Change*, *57*(1-2), 99–118.

D'Agostino, R., Bader, J., Bordoni, S., Ferreira, D., & Jungclaus, J. (2019). Northern Hemisphere monsoon response to mid-Holocene orbital forcing and greenhouse gas-induced global warming. *Geophysical Research Letters*, *46*(3), 1591–1601.