Climate of the Past Discussions

Clim. Past Discuss., referee comment RC2
https://doi.org/10.5194/cp-2021-75-RC2, 2021

Comment on cp-2021-75

Anonymous Referee #2

Referee comment on "Effect of nitrogen limitation and soil biophysics on Holocene greening of the Sahara" by Jooyeop Lee et al., Clim. Past Discuss., https://doi.org/10.5194/cp-2021-75-RC2, 2021

The manuscript "Effect of nitrogen limitation and soil processes on mid-Holocene greening of the Sahara" by Lee and colleagues aims at exploring the climatological and environmental conditions that enabled the existence of a Green Sahara at the time of the transition between Early to Mid-Holocene using a well-established ESM. To that end, a set of different scenarios were simulated to investigate the role of soil properties, nitrogen availability, and orbital forcing parameters on the extent and productivity of the Green Sahara vegetation.

I was looking forward to reading the study because the topic personally interests me and the conditions that caused the Mid-Holocene Sahara greening are still not entirely understood. Topic-wise, the study in my opinion fits the scope of the journal. However, while reading the manuscript, a variety of aspects remained unclear or confusing to me and I suggest the authors rework the manuscript before it can be published. It is rather short, which is in itself not a bad thing, but unfortunately, it also feels to me like parts are missing that would be essential to make the story round and consistent. In particular, the introduction would benefit from a clear statement of research questions to be addressed in this study that are then picked up and answered either during the presentation of the results or during a discussion following the results. There is hardly any discussion of the results in a broader context, neither regarding the limitations of the study (and in my opinion, there is a considerable limitation there that ought to be addressed – see specific comments regarding precipitation-vegetation relationship) nor to put the results found in this study in a broader context with regard to the findings of other studies (simulation studies as well as empirical studies based on proxies or similar). I'm afraid to say that in its current state, the manuscript to me reads more like an advanced draft than a final presentation of the study due to these general limitations.

Language-wise, the manuscript is not too hard to understand but would benefit from language editing to erase grammatical/stylistic mistakes. I have pointed out some of these in the technical remarks, but obviously, not everything that would benefit from language editing. Maybe consider having a native speaker go through it for you before submitting the final version.

Specific comments:

l. 47/48: "Furthermore, vegetation in the GS led to more simulated organic matter in soils and therefore affecting hydraulic, thermal, and radiative properties of soil." => From the context, it's not entirely clear whether you are referring to our own study, or another previous study (which I assume you do). If the latter is the case, add the reference to make it clear that you are referring to work that has been conducted previously.

l. 48: soil texture changes: Be careful with terminology here and in other places in the manuscript: Texture is a quality that refers to the grain size distribution of the mineral soil component, usually represented by giving the mixing ratio between the grain size classes sand, silt, and clay. Texture normally does not change due to biological processes, only through geological processes such as weathering, erosion, and deposition/accumulation of material. Adding soil organic matter (SOM) to the soil therefore will not change texture, although it affects soil properties such as bulk density, aggregate formation, size and stability, and water holding capacity.

l. 52-56: So this is in the first place a model calibration study? That's the impression one gets from reading this paragraph. It's rather vague. I think you should specifically state the research questions that you have regarding the GS and that you are attempting to address in this study. And, consecutively, later on, present your answers and conclusions regarding these research questions in the results and discussion section of the manuscript. It would help the reader to know what to expect, and where the focus of this study will be.

l. 66 "… and CFexess is the excess of carbon fluxes…" => Definition? What does it mean/what is the reference basis - Please verbally clarify the context of "excess" here so that it is more clear where you are heading to/what you are demonstrating with the following equations. E.g., "CFexcess is the amount of carbon that plants could additionally allocate if nitrogen were not limiting."

l. 70, Eqn. 3: kn_alloc/kc_alloc => Is the purpose of this term to aim for a target C/N ratio in plant tissue?

l. 70: Nretrans: Not clear to me what "retranslocated" is? Nitrogen re-allocated within the plant from one compartment to another? Please clarify.

l. 83: "surface albedo is irrelevant to soil moisture" => I guess you mean the other way around: "soil moisture is irrelevant for surface albedo…" or better "surface albedo is not influenced by soil moisture".

l. 88, Eqn. 9: Delta becomes negative at theta1 > 0.275. What do you do at water contents > 27.5%? Assume the soil does not get darker any further than the value set for alpha_sat?

l. 89/90 What is the range of albedo values associated with these classes, i.e., what is the albedo of the lightest, and what is the albedo of the darkest soil? Just to get a feeling for the range. And: is this albedo for the classes equal to alpha_sat or the alpha of nearly completely dry soil?

Experimental design and results section: Use past tense to describe your methodology and results. On the use of tenses in scientific writing, see the explanation given here:

https://www.unl.edu/gradstudies/connections/writing-about-your-research-verb-tense

Experimental design description - general note: What does not become clear to me is whether the control simulations were conducted with nitrogen cycling turned on or off, i.e., whether nitrogen limitation played a role or not. I'm also not sure whether the 8K simulation is the control scenario, or if the 8K scenario was with nitrogen limitation and there was yet another 8K simulation without N-limitation. Looking at the results, it looks like the 8K simulation was also conducted under consideration of N-cycling/N-limitation, but clarification on that aspect in section 2.2 would help. Looking at Figure 6 with the two difference-maps for both 8K and 8KCN that both show N-limitation induced GPP reduction suggests to me that there must be a non-N-limitation control for 8K, otherwise it would not be possible to determine the effect of N-limitation on GPP in that way? The scenario configuration with respect to N-limitation and whether there was a control that had no N-limitation should definitively be clarified in the methods section.

l. 97: "The MH period is set to 8000 years ago (8K) in this study" => Terming it "Mid-Holocene" is then a bit misleading, because the Mid-Holocene normally is attributed to the time period between 7000-5000 BP, centering around 6000 BP (https://www.ncdc.noaa.gov/global-warming/mid-holocene-warm-period).

l. 101: "… soil texture change to loam iss added to the 8KCN in the 8KCNS" => see comment for line 48 – soil texture is unlikely to change from sand to loam, and definitively not because of more SOM. It will still remain sand, even if it is sand with a high content of organic material mixed in. The organic material does not add more silt and clay to the sand. As a sensitivity study, it is maybe okay to conduct this experiment, although I do not understand why the effect of SOM on soil bulk density, hydraulic capacity, and other soil properties is not directly accounted for as a process in the model. If it is not, then this should be stated, and explained that using loam is a surrogate to mimic the behavior of sandy soil with increased SOM.

l. 103-106: "It is reasonable to consider more soil carbon and nitrogen in the GS than in the present-day Sahara, because of their close coupling with biomass..." => I'm not entirely sure I understand this correctly: did you entirely prescribe higher C and N content in the soils, or only as an initial condition, and then you let soil C and N evolve dynamically due to the vegetation and organic matter decomposition you simulated? Where vegetation is present, organic matter should automatically accumulate in the soil and lead to an increase in C and N over time?

l. 111-113: Short justification why these three areas are critical/what makes them critical? Are they particularly sensitive to tipping behavior, and if yes, why? Do they have a special role for feedback in the climate system?

l. 114 I'm missing section 3, and stumbled when reading because I first had to notice that this is now the results section. Please add a formal section "3. Results", with a brief general introduction to your results.

Figure 3: Maybe this is just a personal matter, but for the wind field difference in panel h), I find it a bit difficult to grasp the difference and mentally translate it back into what the actual wind field would have looked like. Here I'd find it easier if you showed the actual 8K wind field next to the 0K wind field. At least for me, it's easier to see the difference between both absolute fields than to re-translate the difference into the actual field.

l. 117 "increases" => Same as for methods section: report results in the past tense. They won't change anymore.

l. 122 "the increase in air temperature is not substantial" => What does that mean in more concrete terms? Statistically non-significant?

l. 138 ff: The precipitation minimum allowing vegetation growth is excessively high at 577 mm/year! This is the amount of precipitation typical for more arid savannas, not even grasslands. If the model does not manage to produce any substantial vegetation below this threshold, I see a fundamental issue there that quite heavily impacts the meaning of this study. You make nitrogen availability, or limitation thereof, responsible for the ability of the model to simulate the GS or fail to do so. But how can you be sure it is the nitrogen availability if, in fact, the water-vegetation linkage is so strongly off? In my opinion, this is not only an uncertainty that has not been clearly discussed in previous studies, it is rather an impediment to the aim and scope of your study. In addition, I wonder why nobody has looked into that problem and tried to find the reason behind it if it has obviously been noticed in previous studies. It seems to me that this problem needs urgent fixing. Have you ever checked on water use efficiency (WUE, annual GPP/annual transpiration per unit area)? I suspect that WUE is likely way off compared to remote sensing benchmarks. Or alternatively, that the SPA continuum (soil-plant-atmosphere continuum) is somehow poorly represented/broken. Or that drainage/runoff is too high so that the water is gone before it becomes accessible for the plants. In any case, even if it is not possible for now

to fix this issue, it should be discussed in detail with regard to its implications for the current study, and what the study can reveal in the light of this deficiency in the model.

l. 157 "...results from less downregulation due to…" => "… results from reduced N-limitation on photosynthetic C-gain and GPP… "

Fig. 6: These are both 8k results in reference to results without nitrogen limitation, so there must have been an 8k run that had no nitrogen limitation? This is the first time such a control is suggested (one may guess it must have been done based on the figure). If so, it should be stated more clearly in the methods section and added as a control scenario in Table 1. Figure caption: I'd rather call that "fractional GPP reduction" than "downregulation fraction". And I'd personally reverse the color scheme (higher fractions mean less reduction means lighter color?). In addition, an additional diff-map between a) and b) may show more clearly where and by how much GPP was enhanced due to the additional nitrogen in the 8KCN scenario (for example, b divided by a, or b-a).

l. 173 "… the soils in the GS were loamier because of the larger organic matter in soil,…" => As stated earlier: Loamyness is NOT defined by soil organic matter content. It depends on the mixture ratio between sand, silt and clay, i.e., the inorganic component of the soil. And that was very likely not much different from today. Being richer in SOM does NOT mean loamier. However, it does affect soil bulk density, aggregate formation, hydraulic and thermal properties, and probably also albedo. So in that regard, your assumptions regarding the sensitivity study are valid. Just change the "loamy" part to not tie these changes to texture. Or did you have no other way to mimic the changes in soil properties caused by more SOM than using loamy texture as a surrogate? In this case, it should be explicitly stated and discussed with regard to its validity.

l. 177 "… leads to significant changes in vegetation and climate…" => Statistically significant at what level? And is it significant for all your subareas, or only specific ones?

l. 179: "a change from sandy to loamy soil leads to an increase in soil porosity" => The difference in porosity is comparably small (0.437 for sand and 0.463 for loam according to USDA soil texture classification). What matters more is the difference in saturated hydraulic conductivity, which is more than one order of magnitude lower for loamy soil compared to sandy soil (5.040 m/day for sand, 0.317 m/day for loam), which implies that water drains way more slowly from a loamy soil as opposed to sandy soil. (see Tab. 3 in DOI 10.1007/s11269-013-0295-2)

l. 180: "These changes lead to an increase in net radiation" => maybe rephrase? "… led to enhanced absorption of radiation…"?

l. 184 Rephrase. This sentence is hard to read.

l. 188 ff. I'm not so sure that this is the actual cause behind the Sahara greening. I see a major problem with the model not capturing the vegetation-precipitation relationship in the first place. If the model does not simulate savanna or grassland at ca. 500 mm annual precipitation, then in my opinion this has a far larger effect than the effect caused by nitrogen limitation. Moreover, more vegetation due to more precipitation is required to increase soil nitrogen content compared to non-vegetated state due to N-fixation and N-input and accumulation in the soil as a consequence of biomass decomposition and turnover. Vegetation and N availability therefore can be expected to have built up correlated with each other.

l. 195 general note:

Entirely missing: a discussion section with an in-depth discussion of the results and putting them in the broader context of other studies conducted on the GS-topic, both simulation studies, and proxy-based studies. Also no discussion of limitations of the current study, e.g., the poor representation of precipitation-vegetation cover linkage and its implications. This ought to be addressed.

Too many details are missing in this paper the way it is currently written so that it is in part hard to read without having to guess on background information. For example, it is not clear whether the 8K simulation had more or less nitrogen than the 8KCN simulation, i.e., whether that simulation was with or without nitrogen cycling considered. And if nitrogen cycling was considered in the 8K simulation, then it's not clear whether there was also a baseline simulation for 8K that had no N-limitation (N-cycling turned off), as may be inferred from Fig. 6., which must have a reference base that is not clear.

l. 208 “interactive changes in soil texture” => I’d rather say: “process-based dynamics of soil properties”

l. 208/209 “Notably, our findings and their implications can be extended to the future climate simulations” => How exactly? This is rather vague and general, it would be nice to have more details.

General note: “Mega Lake Chad” => to my knowledge, officially it’s called “Lake Mega-Chad”?

Minor corrections/technical remarks:

l. 31/32: "Our future climate prediction is made…" => "Future climate predictions are made…" - otherwise it reads like you are trying to make future climate predictions in this study, which is misleading.

l. 32: "In these respects" => "In this context"

l. 35: "Many modeling studies have been tried…" => "Many modeling studies have tried…"

l. 45/46: "… global carbon budget has been better captured by its downregulation effect of terrestrial GPP…" => "...the representation of the global carbon cycle has improved due to accounting for the N-limitation effect on GPP…"

l. 47 "… and therefore affecting hydraulic…" => "…, which affected hydraulic,…"

l. 80 "… is listed in Supplement" => "… are listed in the Supplement"

l. 99/100: "...examine the impacts soil nitrogen,…" => "examine the impacts of soil nitrogen,…"

l. 101: "...loam iss added…" => "… loam is added…"

l. 117 "...than the present…" => "… compared to the present…"

l. 120 "This intensified land-sea thermal contrast yield spatial changes…" => "This intensified land-sea thermal contrast caused spatial changes…"

l. 122 "… because the increase in…" => "...because of the increase in…"

l. 123 "meridional wind" => "the meridional wind"

l. 125 “This ITCZ shift made a favorable condition…” => “This ITCZ shift caused a favorable condition…”

l. 126 “...in both of the…” => “… to both the…”

l. 134/135 “...extended more up north to…” => “… extended as far north as…”

l. 135 “...to proxy data…” => “...to the proxy data…”

l. 136 “… in western Africa and southern border…” => “… in western Africa and the southern border…”

l. 145 “… that Mega-Lage Chad does not make substantial changes…” => “… that Lake Mega-Chad did not cause substantial changes…”

l. 159 “increases about by” => “increases by about”, or “increases ca.”

l. 182/183 “in the North Africa” => “in North Africa”, or “in northern Africa”, or “in the north of Africa”

l. 136 “… that the evapotranspiration increase in the Sahara-Sahel region made an increase…” => “… that the evapotranspiration increase in the Sahara-Sahel region caused an increase…”

l. 188/198 “...vegetation change increases precipitation with enhanced evapotranspiration…” => due to enhanced evapotranspiration

l. 203 “thus making vegetation cover and GPP increases” => “thus making vegetation cover and GPP increase”

l. 205: “through the albedo-precipitation.” => “through the albedo-precipitation feedback.”