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Interactive comment on "CO_2 fertilization effect can cause rainfall decrease as strong as large-scale deforestation in the Amazon" *by* Gilvan Sampaio et al.

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We take this opportunity to genuinely thank the work done by the two anonymous reviewers, which has substantially improved this new version of our manuscript.

Obs: line numbers mentioned in the referee's comment refer to line numbers in the previous manuscript version, whereas the line numbers mentioned in the response to each comment refer to line numbers in the new manuscript PDF file.

New figures and tables are added in the response to Referee #1

IMPORTANT STATEMENT When attempting to respond to the referees' comments

we realized that some of the variables requested to be shown in the article were not saved or stored properly. As such we had to carry out new simulations such that we could properly save and show the requested variables. In that process we noticed that there were some differences in the Deforestation scenario results, especially regarding rainfall anomalies (which instead of -0.8 mm d-1 is in fact -0.5 mm d-1), and minor numerical updates in the other variables [although average precipitation reduction in the Physiology scenario is stronger than in the Deforestation scenario, the variability range of anomalies in both scenarios do not indicate a significant difference between the two mean values (as can be seen in Fig. 3a) and because of that we keep the article's title and conclusion]. We attribute this confusion regarding changing values in the Deforestation scenario to a recent substitution of processing blades at INPE's (Brazil's National Institute for Space Research) supercomputer, where these simulations were carried out. The new model runs do not change in any way the previous conclusions of the article and in fact are more trustworthy, for example in regard to the obtained changes in radiative balance and accompanying surface temperature changes which are now more consistent in the deforestation scenario. We sincerely apologize for the inconvenient.

Anonymous Reviewer #2

Major Comments:

1. "Is it a coincidence that 1.5xCO2 and 100% substitution to grassland give similar results? Why were these values chosen to compare? Why not 2xCO2 or 50% substitution to grassland? Some motivation for this specific comparison is needed. For example, when in the future would we expect to reach 1.5xCO2 based on the current trajectory of emissions, and how does that compare to the timescale of deforestation based on current deforestation rates?"

R: The thank Refereee #2 for point out this caveat in our manuscript and providing us the opportunity to make it clearer in that regard. The following text has been added to the Methods' subsection 2.2 Modeling protocol (line 126):

"The selection of such scenarios started first with the intention of understanding the impacts on moisture fluxes and rainfall in the Amazon driven by the target concentration to be used in the AmazonFACE experiment in Central Amazon (Norby et al., 2016). Second, we also wanted to know how the results obtained in the Physiology scenario compared to changes due to an extreme deforestation in the region. Rather than representing realistic projections of the future of the Amazon, this systematic separation of climatic forcings allow us to better understand how each of them contribute to future changes in the region. Notwithstanding, an atmospheric CO2 concentration of +200 ppm (i.e. 588ppm) is projected to be reached short after 2050 under IPCC's RCP8.5 and in 2080 under the RCP6.0 (Vuuren et al., 2011). A complete deforestation of the Amazon basin, following a business-as-usual deforestation-rate scenario – with deforestation rates typical of the late 1990's – could be possibly reached around 2100 (Soares-Filho et al., 2006)."

Moreover, we have added a sentence at the end of the manuscript that it would be probably valuable to perform ensemble simulations with gradual increase of CO2 and deforestation levels, to understand when and how the effects of increasing CO2 and deforestation dominate the rainfall responses in the Amazon region (see line 371).

2. "The meridional mean changes in Figure 4c show increases in column specific humidity along the western side of the Amazon due to physiology, but the moisture transport in Figure 5a and discussion in the text indicate a reduction in the flux to the Andes (2.1 kg/m/s reduction). Likewise, in the deforestation case for the same region, there is a large reduction in low level humidity (Figure 4d), but Figure 5b shows an increase of 10.8 kg/m/s. In order to understand these results, it would be helpful to see what the horizontal wind anomalies look like at different levels? It might also help to decompose the moisture transport changes in order to understand the contribution from changes in humidity vs. changes in circulation."

R: This is a well-noticed point and we thank the reviewer for grating us the opportunity to explain this better as follow (line 215, section 3.2 Atmospheric circulation):

"These changes in horizontal circulation imply, in the Physiology scenario that less moisture enters the Amazon region from the Atlantic (-4.9 kg m-1 s-1), and less moisture leaves the regions towards the Andes (-2.6 kg m-1 s-1)(this latter is somewhat compensated by a stronger moisture convergence from the Pacific to the Andes, Fig. 5b). In the Deforestation scenario there is an increase of the input of humidity to the Andes at the surface level (in the order of 3.0 kg m-1 s-1), which is perceptible also in the west part of the vertical profile of humidity near surface levels (Figure 5d). The lower evapotranspirative capacity aligned with a lower vertical mixing due to pasture's lower roughness length result in an atmospheric volume depleted of moisture and with decreased uplifting of air masses. In the Physiology scenario, despite of the decreased evapotranspirative capacity, the increased surface heating increases vertical mixing at low levels (up to 700 hPa), which is connected to the increase of humidity throughout the free tropospheric volume (above the boundary layer) over the region. However, after such atmospheric height there are strong subsidence anomalies in the Physiology run (Figure 5b), which decreases deep convection that is ultimately associated with lower rainfall rates. The same vertical circulation patterns have been well demonstrated in previous (separate) studies that modeled large-scale deforestation of the Amazon and, more recently, the isolated physiological effects of eCO2 on the region's climate (c.f. Langenbrunner et al. 2019)."

3. "Comparing Figures 6c and 6d, it seems that the evaporation from the soil and canopy are compensating the reduction from transpiration in the deforestation simulation during the wet season. It would be helpful to see what the seasonal cycle of these other evaporation terms look like? What would cause them to increase, despite a decrease in precipitation, in the deforestation simulation? It would also be helpful to see the seasonal cycle of LAI in this figure to better understand the mechanisms described. Likewise, adding annual mean net radiation to Figure 3c (and perhaps the

season cycle of net radiation to Figure 6) would help clarify the mechanisms driving changes in the energy budget and surface temperature."

R: The reviewer is correct. Indeed evaporation is compensating the lower transpiration during the wet season in the Deforestation run, as is now clearly evidenced in Figure 6 and also mentioned in the text of section 3.4 Seasonality (line 258). Notice however that evapotranspiration, evaporation and transpiration are all lower than the control run. While including the seasonal cycle of LAI in Figure 6 is a good suggestion, we opted to not include there in this figure because we found out that there is no seasonal variation of LAI in the vegetation scheme of CPTEC-BAM. The corresponding average LAI changes for each run are now provided in the main text (line 184) and in the newly included Table 2. Annual mean net radiation has been included in Fig. 3c, as well as a panel showing net radiation seasonal cycle in Fig. 6. The results related to the radiation balance are now discussed in an own section (3.3 Radiation balance) on lines 236-249. See also the response to Referee #2's comment 14.

4. "The fact that the two scenarios give similar results is really interesting. It is likely there would be some compensating effects on transpiration if they were simulated together (transpiration would decline by less than the two added together), but it is less clear what the impact on circulation would be. It would be very interesting to add a third scenario in which both elevated CO_2 and deforestation occur together. There are several places in the manuscript that refer to a "Full" simulation which is not shown in the figures, is that referencing this combined scenario?"

R: Please see the response to Referee #1's comment 1.

Minor comments:

5. "Line 26: What specifically is "its dry-season lower surface vegetation coverage" referring to aside from the "decreased leaf area index" that is already mentioned?"

R: Indeed, the phrasing was redundant and now is restricted to "(. . .) smaller leaf area

index in Deforestation" (see line 26).

6. "Line 80: Suggest changing "majorly in" to "mostly on"."

R: Suggestion accepted (see line 84).

7. "Line 108: Does the vegetation component of CPTEC-BAM allow for increases in LAI, without a change vegetation type, due only to higher CO_2? Or is it only the impact on stomatal conductance?"

R: Yes, the vegetation component of CPTEC-BAM allows for increases in LAI, without a full change in the vegetation type. For sake of clarity we have rephrased the mentioned sentences to:

"The numerical experiments employed here include simulations considering the increase in the concentration of atmospheric CO_2 affecting plant physiology and experiments considering deforestation in the Amazon as follow (. . .)"

8. "Line 110: Suggest changing to: "Control run with an atmospheric CO_2 concentration of 388 ppmv." "

R: Suggestion accepted. The sentence now also includes complementary information about the way vegetation is modeled in the control runs to be compared with Physiology and Deforestation scenarios (line 116):

"Control runs with an atmospheric CO_2 concentration of 388 ppmv, one with dynamic and another static geographical distribution of vegetation types (for comparison with Physiology and Deforestation scenarios respectively)."

9. "Line 116: Should this be "climatological mean" or "climatological mean annual cycle"? Often the seasonal cycle is retained in prescribed SST simulations, is that the case here?"

R: Sea surface temperature (SST) was represented as the fixed climatological mean annual cycle from the period of 1981-2010 and, as such, it considered SST seasonal cycle. The information was included in the text (line 135).

10. “Line 117: What does it mean that "vegetation distribution could vary"? Does this mean that a forest can become a grassland interactively? Does the model represent disturbances like drought and fires that are needed to drive this transition?”

R: We meant that the geographical distribution of vegetation types can change according to variations of climate. The model simulates both grass and trees PFTs coexisting in a grid cell and disturbances such as fire are represented by a fixed percentage of the biomass of all PFTs that is reduced every year (this information is now included in line 91). So, depending on the environmental conditions (e.g. climate), in extreme cases, a forest could indeed become grassland. Nevertheless, as mentioned in the same sentence, there are no significant changes of vegetation in the Physiology scenario that are worth analysis in the article. Anyhow, the information is kept for sake of reproducibility [not without specifying that it is the “geographical distribution of vegetation types could vary throughout the model run (. . .)” (see line 135)] .

11. “Line 135: What is the region averaged over in Figure 3? Is it the entire region shown in Figure 2 or just the Amazon? You could add a box to figure 1 or 2 showing the region. This should be stated in the figure caption as well.”

R: In fact there is a mention in that sense Fig. 3 caption (line 622):

“(. . .) from the CPTEC-BAM over the Amazon region (black line square area in Fig. 5). . .”

12. “Line 138: How do you know the "reduction in precipitation leads to an increase in regional temperature" and not the other way around? From the experiment, it seems more likely reduced ET leads to higher temperature and lower precipitation, and the temperature and precipitation changes likely feedback on each other. I suggest using language such as "is associated with" rather than "leads to". I suggest being careful about causal relationships throughout the manuscript.”

R: The suggestion is pertinent and we have accepted it throughout the manuscript, giving preference to terms like “is associated with” or “is combined with” instead of “leads to” or “causes”. Regarding the relation between ET, temperature and precipitation, please see the response to Referee #1’s comment 5.

13. “Line 140: What is the 3rd scenario?”

R: Please see the response to Referee #1’s comment 1. We try to restrict mentions only to Physiology and Deforestation scenarios, as these compose the main focus of the article.

14. “Line 143: It would be helpful to include the net surface radiation term as part of Figure 3c. Or even the up and down terms for short and longwave radiation. In the deforestation simulation, latent heat goes down, but sensible is mostly unchanged, which implies net radiation also goes down. Do you know why? Is it just due to the surface albedo change or are there changes that might impact other terms as well, such as cloud cover?”

R: Net surface radiation is now included in Figure 3c. The updated model runs now show that in fact there is a decrease also of sensible heat (-1.34 W m-2) in the deforestation run, resulting in negative net surface radiation balance in the deforestation run, that is associated with a small decrease in average 2m-air temperature. The following text now composes a new article’s subsection (3.3 Radiation balance) starting in line 236:

“A decrease in surface sensible heat (-1.34 W m-2) in shown the Deforestation run (Fig. 3c), which alongside with a decrease in latent heat result in a negative net surface radiation balance in the deforestation run, that is associated with a small decrease in average 2m-air temperature (-0.2 °C). On the other hand, in the Physiology scenario there an increase in sensible heat (+3.96 W m-2) that is associated with an average increase in 2m-air temperature of +2.1°C. While the decrease in latent heat is also directly connected to a lower evapotranspiration, the opposite results shown in each scenario regarding sensible heat is associated with also opposite changes in near-surface atmospheric circulation patterns: in the Deforestation run there is a increase in near-surface atmospheric advection, whereas in the Physiology scenario this advection is considerably decreased (as explained in section 3.2 Atmospheric circulation). Statistics on short- and long-wave radiation at/from surface are presented in Table S1. Shortwave radiation is increased due to decreased nebulosity in both model scenarios (Physiology: -1.4%; Deforestation: -2.2%), but such an increase in shortwave radiation balance is stronger in the Deforestation scenario due to the albedo change. The same pattern is also obtained for the surface balance of longwave radiation, which increases in both scenarios, but more strongly in the Deforestation (Physiology: 2.7 W m-2; Deforestation: 6.9 W m-2), which is probably a combination of lower evapotranspirative capacity and increased horizontal advection in the latter scenario."

15. "Line 147: Again, I don't think "yields" is a good word choice because it implies a causal relationship, which is not shown. I would think the "reduction of moisture convergence" yields "decreased precipitation" and not the other way around."

R: We thank Referee #2's patience in also noting this point. We have substitute the term "yields" by "is associated with". The phrasing of the mentioned sentence is now changed as shown in the response to Referee #1's comment 6.

16. "Line 153: What is the change in "gross primary productivity" in these simulations?"

R: The changes in GPP are now shown in Fig. 6, Table 2 and in the presentation of results in the main text (line 177):

"The effect that a higher CO2 concentration has in reducing gs (Eq. 1) overcomes the positive effect of increased gross primary productivity (GPP) (Physiology: +7.0 μmolCO2 m-2 s-1 (+58%); Deforestation: -1.0 μmolCO2 m-2 s-1 (-16%) in gs (...)"

17. "Line 157: What is the "Full" run mentioned here? "Full" is not a simulation mentioned earlier or in Table 1."

R: Please see the response to Referee #1's comment 1. Table 1 now explicitly includes the RCP8.5+Def scenario.

18. "Line 162: Figure 4 is not referred to in the text. It should be referenced somewhere before Figure 5."

R: Two mentions to Figure 4 are now made in section "3.1 Provision of humidity" (lines 179 and 183).

19. "Line 167: Could you show the impact of "decreased roughness length of surface" quantitatively? How does the boundary layer height change overall? What is the influence of roughness length vs. higher temperatures and heating on vertical mixing?"

R: We now include a figure in the article's supplement (Fig. S5) showing the meridional mean planetary boundary layer height at the equator over the Amazon. We see that in the Deforestation scenario there is an average decrease of 10% in the boundary layer height, attributable to the considerably lower surface roughness length of pasture compared to a tropical forest. On the other hand, there is an average increase of 21% in boundary layer height in the Physiology run, associated with the increased heating of surface. This explanation is now given on main text line 202.

20. "Line 171: Again, there is reference to a third scenario." R: Please see Referee #1's comment 1. We have excluded the mention to the third scenario given that Physiology and Deforestation scenarios are the main focus of this article. Additionally, we make now an explicit reference to Fig. 3c and Table 2 in this specific part of the text (line 213) to help the reader find the results linked to the information provided in the mentioned sentence.

21. "Line 173: What do the horizontal wind anomalies look like at different levels? It might help to decompose the moisture transport changes in order to understand the contribution from changes in humidity vs. changes in wind." R: Please see the response to Referee #2's comment 2 above.

22. “Line 182: This section also references a third "Full" simulation not shown in the figures or described in the text/table.” R: Please see Referee #1’s comment 1. Additionally, we make now an explicit reference to Fig. S4a to help the reader find the results linked to this information (line 253).

23. “Line 188: To understand the seasonality of the precipitation changes, and differences between wet and dry seasons, it would be useful to assess the circulation changes and moisture transport at a seasonal timescale as well. For instances, are the circulation changes due to eCO2 larger than deforestation during the rainy season, leading to a larger decrease in precipitation from Oct to Dec?” R: While we agree with the Referee that the seasonality of changes is important, we do not include such an analysis of the seasonal changes of atmospheric circulation and moisture transport because it has been already shown, for example by Kooperman et al. (2018) that the Physiological effects of eCO2 on the region’s climate take place namely in the wet season, when GPP and gs/transpiration are higher (see Fig. 6d and h), even though our results also show considerable rainfall reduction during the dry season. Conversely, it has been demonstrated (e.g. Lawrence & Vandecar 2015) that large-scale deforestation causes climatic changes namely during the dry season, when transpiration is particularly reduced, as also shown in our results (Fig. 6a and d). This explanation is now provided in the main text’s section 3.4 Seasonality (line 263).

24. “Line 189: I’m not sure the ET changes explain the moderate increase in temperature due to deforestation because it is more moderate throughout the year, including the dry season when ET decreases more than in the physiology simulation.” R: The reviewer is correct. The sentence has been eliminated. A new sentence has been included in the previous section (line 210) that we believe explains better the mechanism behind the moderate increase in temperature in the Deforestation scenario:

“On the other hand, the strong increase in westward moisture advection, aligned with the increased albedo and decreased vertical mixing (Fig. S5) seems to best explain the nearly unchanged surface temperature in the Deforestation scenario.”

25. “Line 198: Figure 6c shows a decrease in ET, but this sentence states that evaporation increases. I think the decrease in soil water in the physiology simulation is probably due to the decrease in precipitation, since ET decreases all year round.” R: Please see the response to Referee #1’s point 7.

26. “Line 200: It would help to show the seasonal cycle of LAI or vegetation coverage in these simulations. That would help explain the seasonal pattern of ET and soil wetness better, particularly for the deforestation run. This could be added as a panel to Figure 6.” R: Please see the response to Referee #2’s comment 3 above.

27. “Line 212: The "strengthening of the Walker cell over the Amazon" is not shown in the results. I suggest adding a figure that shows the full vertical-zonal wind anomalies.” ‘R: Please see the response to Referee #2’s comment 2 above

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