



EGUsphere, author comment AC2
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Reply on RC3

Isobel M. Parry et al.

Author comment on "Evidence of localised Amazon rainforest dieback in CMIP6 models" by Isobel M. Parry et al., EGU Sphere, <https://doi.org/10.5194/egusphere-2022-82-AC2>, 2022

We would like to thank the reviewers for their constructive feedback and appreciate their contribution to improving the article. Please see below for answers to the specific points raised in the reviewer comments. Reviewer comments are listed in italics and our responses are shown in bold font.

To give one example, the authors mention that some of the diebacks are mediated by fire, but from reading the manuscript it is unclear which models predicted dieback due to fire, which models predicted dieback due to physiological/hydraulic failure, or even if the models that resulted in no dieback were also the ones that did not have fire.

Reply: Information on which models have fire will be given in Table 1 and be added to the discussion. "Some models have fire present, such as EC-Earth3-Veg, GFDL-ESM4 and MPI-ESM1-2-LR, while others do not (e.g., UKESM1-0-LL). It is interesting to note that UKESM1-0-LL, which experiences no dieback shifts, also has no fires simulated within the model. However, the role that fire plays in inducing vegetation dieback in these models requires further experimentation and work."

Introduction. There are many studies that investigated the risk of critical transitions specifically in the Amazon, and it may be worth including them to provide a stronger motivation for this work. As a starting point, the recent Amazon assessment report (<https://www.theamazonwewant.org/amazon-assessmentreport-2021/>, chapter 24) has an extensive review on this subject.

Reply: In order to provide a stronger motivation for the work the paragraph starting on line 49 will be expanded to read:

"A recent study, using CMIP5 models, determined that Amazon dieback, under the high emissions scenario RCP8.5, is not likely to occur in the 21st century but recognises that an increase in anthropogenic deforestation could bring the Amazon closer to a dieback event (Chai, 2021). Meanwhile, other studies predict the Amazon to have a low resilience of forest to climate change, coinciding with human pressures such as deforestation (Hirota, 2011). There is remaining uncertainty associated with the likelihood of a dieback event occurring, stemming largely from uncertainty in the effects of important factors such as the extent of CO₂ fertilization and soil nutrient limitations (Ramming, 2010; Hirota, 2021). In this paper we look at the projections from the latest

CMIP6 Earth System Models for evidence of Amazon dieback and identify a precursor which is based on longer-term temperature records.”

L49-51. This paragraph could be expanded to provide a stronger motivation for this study. The authors could justify why the current analysis is necessary, and how this study contributes to learning something new about the future of the Amazon to climate change.

Reply: As suggested we have expanded this paragraph. Please see the answer above.

Table 1. The authors could expand this table to provide a bit more information of the simulations and models used. For example, they could provide some information about the models (e.g., which ones had fires enabled, which other mechanisms cause mortality and biomass loss), and which variants were used from each model. If citations exist for these models, the authors could add references.

Reply: As suggested, Table 1 will be expanded to include the land surface model, the Transient Climate Response, precipitation change at 2xCO2 and whether fire is represented in the model, as shown below:

Model	Institute	Land Surface Model	Transient Climate Response (TCR) (°C)	Precipitation change to a doubling of CO2 (mm/year)	Fire simulated
	EC-Earth-Consortium	HTESSEL	2.6	-139	Yes
GFDL-ESM4	NOAA-GFDL	LM4.1	1.6	-60	Yes

MPI-ESM1-2-LR	Max-Planck-Institut für Meteorologie	JSBACH 3.2	1.6	-57	Yes
NorCPM1	EarthClim	CLM4.0	1.6	-76	-
TaiESM1	AS-RCEC	CLM4.0	2.3	-60	-
	Seoul National University	CLM4.0	2.3	-282	-
UKESM1-0-LL	Met Office Hadley Centre	JULES-ES-1.0	2.6	-196	No

Section 2.3. I found the early warning section disconnected from the introduction. In the introduction the authors describe the theory of critical transitions, critical slowing down and increase in autocorrelation, yet none of these seem to be used in the actual analysis. Was there any reason for not using these established approaches?

Reply: To address this point we will include supplementary material which

focuses on trialling these generic early warning signals for Amazonia in CMIP6 models. This analysis involved calculating the autocorrelation and variance for vegetation carbon for each grid point and found little evidence that these metrics would work as an early warning signal for these models.

Section 3.1. The authors use savannah as the alternate state for forests, and this can be misleading if fire is not the driver for abrupt changes. Also, this section describes the changes across tropical South America, but the authors do not provide any insight on what causes the variability across models. Presumably they also have broad range of predicted climate, presence/absence of fires, and different approaches to simulate drought mortality. Explaining these differences could help us understanding why there was such broad range in dieback responses.

We will add the following text to the Results and Discussion to address the possible mechanisms behind the differences in detected abrupt shifts:

“Differences between modelled vegetation dieback arise for multiple reasons. Although there is a somewhat reduced spread in the CMIP6 model generation, ESMs continue to project different regional climate changes over Amazonia (Parsons, 2020). Even for the same climate change, models produce a range of tropical forest responses, such as different sensitivities to drying (which is affected by assumptions concerning the rootdepth of tropical trees), different responses to warming (controlled through different optimum photosynthesis temperatures), and different representations of climate sensitive disturbance processes (e.g., fires (Table 1)).

The assumed optimum temperature for photosynthesis has been highlighted as a particularly important factor in mediating the response of tropical forests to climate change (Booth et al., 2011). The vegetation components of ESMs often also have different responses to a given increase in atmospheric CO₂ (Wenzel et al., 2016). The direct physiological effects of CO₂ on the rate of plant photosynthesis and on plant water use efficiency typically counteract the negative impact of climate change on tropical forests (Betts et al., 2004). As a result, the extent of CO₂ fertilization is another important difference across the models (Ramming, 2010).

Abrupt shifts are driven by stochastic variations in each model, which can be either interannually-generated climate variability or the randomness of disturbance events (such as fire), which is assumed in some vegetation models. Where this stochastic forcing is relatively small, the detected abrupt shifts will tend to be spatially coherent and determined by the underlying large-scale patterns of climate change. However, in models where this stochastic forcing is more significant (e.g., EC-Earth3-Veg), detected abrupt shifts tend to be much less spatially coherent. Under these circumstances the detection of an abrupt shift is more dependent on the threshold chosen (see Supplementary Material Figure S1).”

L115–118. My previous comment applies here too. The remark that models largely disagree is correct, but not very informative. I would not expect the authors to provide details about every model configuration and formulation, but I think they could explore some potential causes by looking at other model output data (at the very least precipitation, some insight on model sensitivity to CO₂, and some fire and mortality-related variables if available).

Reply: We will include information on climate sensitivity, precipitation change under global warming and the representation (or otherwise) of fires for each of

the models within table 1 (see above) and also further discussion on the potential causes of differences between the models (see response above).

Section 3.3. I am unable to see the causal link between CO₂ and the abrupt shift based solely on Figure 3. If anything, in GFDL most of the shift in the amplitude of the seasonal cycle seems to occur after the abrupt transition. Also, the difference in the seasonal cycle is very large across models, with NorCPM1 remaining below 4°C for the entire century, whereas the other models show much higher amplitudes. Is it fair to treat the shifts marked in Fig. 3 the same?

Reply: Figure 3 is used to show that the amplitude of the seasonal cycle increases before an abrupt transition in three examples from different models, with potentially different causes of dieback. This figure is used to motivate our investigation to see if these increases are observed at all grid points or primarily grid points that possess a future abrupt transition (Figure 4). We will make this clearer in our revised manuscript.

Discussion: I support keeping the discussion short, but maybe the current one is a bit too short and narrow in scope. For example, the authors mention that the dieback was present in previous generations of model but not in CMIP6. Why is this the case? Also, how does this result differ from the analysis by Cox et al. (2013) (<https://doi.org/10.1038/nature11882>), which had already indicated lower risk of a dieback. Also, the results implied that fire is an important mechanism for dieback, and I think the discussion could emphasise this further, considering that fire activity has significantly increased recently in the Amazon. The mechanistic links between increased CO₂ and dieback (and the uncertainty in these links) could be discussed in more depth too. I think addressing some of these aspects would help placing these interesting results from the CMIP6 predictions in a broader context.

Reply: We will include additional discussion about the reasons for the differences between models, and between model generations in the Results and Discussion section (see above). The analysis by Cox et al. (2013) concerned a proposed emergent constraint on the loss of tropical land carbon with global warming. It did not specifically look at abrupt changes in forest cover. While our study shows little evidence of abrupt large-scale land carbon loss in CMIP6, it does find evidence for multiple localised abrupt shifts. We will make this distinction clearer in the revised discussion.

Minor Points

L9. I am not sure I followed this sentence. Does this mean that an additional 7% of the NSA will experience dieback for every 1°C above 1.5°C (i.e., if the temperature change is 2.5°C, dieback will occur at 14% of the NSA, if the change is 3.5°C, 21% of the NSA will suffer dieback and so on?)

Reply: Regarding the statement on line 9, the reviewer is correct in thinking that this refers to an additional 7% (with an error margin of 5%) of the NSA region experiencing dieback per 1°C above 1.5°C. For clarification we will change the sentence to read:

"Based on the ensemble mean of the detected dieback events we estimate that 7+/-5% of the NSA region will experience abrupt downward shifts in vegetation carbon for every degree of global warming past 1.5°C."

L49. Quantify "fairly short observational records"

Reply: The sentence on line 49 will be changed to include a more quantitative statement as below:

“These recent studies (Boulton et al., 2022; Luo and Keenan, 2022) focus on fairly short observational records of less than 60 years.”

L55. Include references that describe both CMIP6 and the 1pctCO2 runs.

Reply: As requested, the references for both CMIP6 and the 1pctCO2 runs will be included:

Meehl, G. A., Moss, R., Taylor, K. E., Eyring, V., Stouffer, R. J., Bony, S. and Stevens, B.: Climate Model Intercomparisons: Preparing for the Next Phase, EOS, Transactions American Geophysical Union, 95(9), 77–78, doi:10.1002/2014eo090001, 2014.

Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J. and Taylor, K. E.: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, Geoscientific Model Development, 9(5), 1937–1958, doi:10.5194/gmd-9-1937-2016, 2016.

L67. “Unforced control run” was not described up to this point. Consider describing it in section 2.1

Reply: To address this point we will clarify the PIControl run as an unforced control run in section 2.1, line 56 as below:

“Data from the unforced PIControl runs were also used to determine each model’s internal variability.”

L78–81. This seems to be out of place, it reads more like the caption of Figure 4 (which is referred to before Figures 1–3). Perhaps rewrite this to focus on how sensitivity and dieback risk were calculated.

**Reply: As suggested, the text in lines 78–81 will be rewritten as follows:
“To assess the risk of an abrupt dieback shift occurring the percentage of grid points that experience abrupt dieback out of all grid points with sensitivities within a specified range is calculated. This gives a measure of how likely it is for a grid point with a specific sensitivity to experience a dieback event.”**

L87–90. This text repeats what was described in the methods section. I suggest dropping it.

Reply: As suggested, we will drop the repeated text in lines 87 to 90.

L105–111. “Jumps” seems a bit too colloquial, and it is unclear how it differs from “abrupt shifts”, which is defined in the methods.

Reply: To address this point we will rewrite the two instances where “jumps” is used to read “abrupt shifts”.

L175. “Study” is misspelt.

Reply: Indeed – thanks for spotting. We will correct “stufy” to “study”.

Figure 2. In panel (a), I suggest keeping only NSA, as this is the only specific region analysed in this study. Also, make the labels consistent with captions (e.g., use either abrupt shift or dieback shift), and define the acronyms (AS, cVeg) in the caption.

Reply: As suggested, we will change Figure 2(a) to only include the relevant NSA

region. The acronyms AS and cVeg on the axes of Figures 2b,c will be replaced by abrupt shift and vegetation carbon, respectively, and dieback shift replaced by abrupt shift in the caption for consistency.

Figure 3. Why did the authors show different points for each model? Also add "W" after the last 60°.

Reply: The points mentioned by the reviewer were examples chosen to illustrate several different forms that dieback behaviour can take in the models. This will be clarified by editing the figure 3 caption as follows: "Example time series of selected dieback shifts for three model..."

As suggested, the caption will also be corrected to include the W after the final 60°.

Figure 4. I recommend adding a colour legend to the figure.

Reply: We will be removing the green, blue and orange points representing non-dieback abrupt shifts in Figure 1 and changing them to purple points in Figure 4 to allow for clearer analysis. We will also include a colour legend for the red and purple points in Figure 4.