We thank the reviewer for taking the time to review our manuscript and provide constructive comments.

In revising our manuscript, we noted that our model simulations had used a fixed pre-industrial nitrogen deposition rate. In our resubmission, we reflected that it would make more sense to show results from LPJ-GUESS with the nitrogen cycle switched off. This was because the principal aim of our paper was to explore the sensitivity of the carbon cycle to 'expressions' of El Nino and we might expect that this sensitivity would be greatest using the C-only version of LPJ-GUESS as carbon uptake is not limited by nutrient availability (which may decline with water availability in dry years, when nitrogen immobilisation rates increase). Nevertheless, as one of our main regions of interest was the tropics, we would not expect a strong limitation by nitrogen (Vitousek et al. 1984) and as a result, we do not anticipate a strong sensitivity in our results to our choice of biogeochemical cycle. To assure the Editor/Reviewer of this insensitivity we have shown the results of both cycles (N-cycle on/off) below (Fig 1). We also used this opportunity to update the model comparison against the more recent TRENDY v7 runs.

Overall, we found that LPJ-GUESS is close to the TRENDY v7 ensemble mean and simulations are mostly within the model range (i.e. across TRENDY models) when we switch the nitrogen cycle off. The spatial distribution of the summed composite GPP anomalies (see fig. 2) shows that LPJ-GUESS picks up the main anomalies associated with EP El Nino events and remains within the TRENDY models' range. Finally, LPJ-GUESS has a strong negative bias in Australia. As our results show, Australia does not make a large contribution to long-term changes in any of the carbon fluxes and pools.

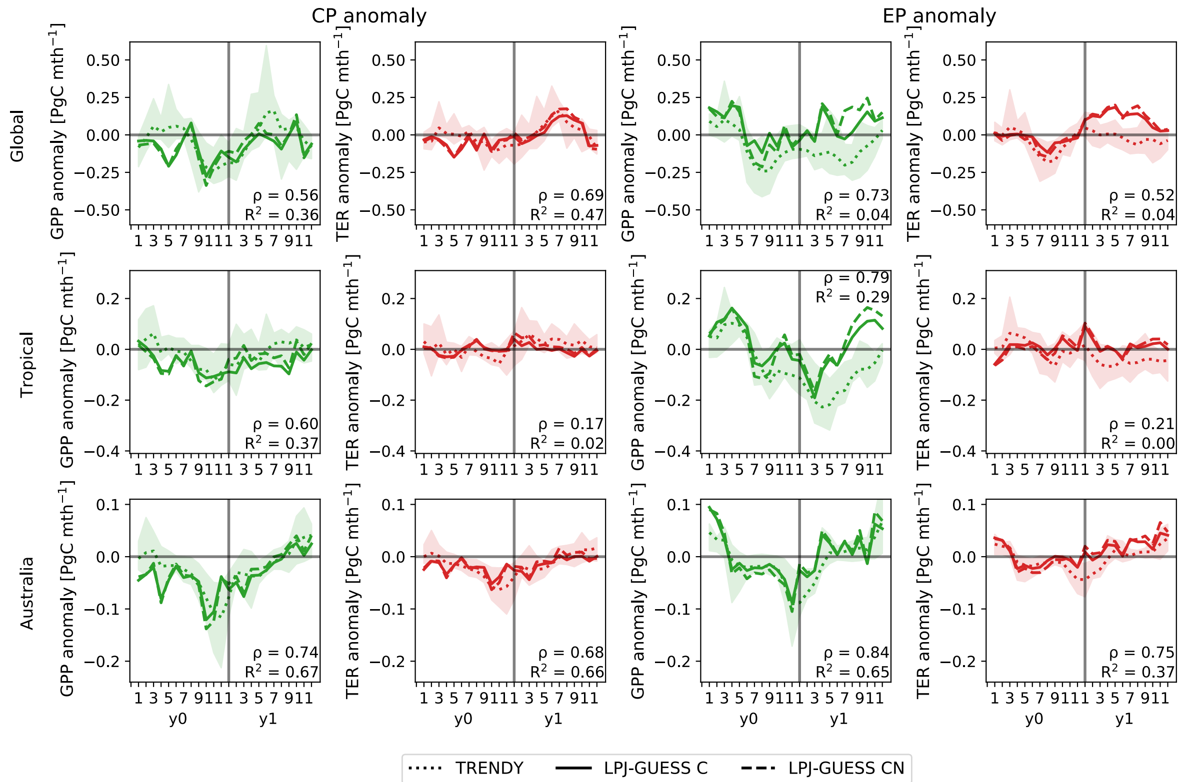

Fig. 1. Monthly composite anomalies during the El Nino developing (y0) and decaying (y1) year in gross primary production (GPP; green lines) and terrestrial ecosystem

respiration (TER; sum of autotrophic and heterotrophic respiration; red lines) for all CP and EP El Nino events listed in appendix table A1 averaged over the globe, the tropics (23°S–23°N) and Australia. The dotted lines show the TRENDY v7 composite, the solid lines are the individual LPJ-GUESS run where we switch of the nitrogen cycle, the dashed lines show the model runs with dynamic nitrogen cycling (compare Wang et al., 2018). ρ and R^2 show the correlation coefficients and R^2 values between the LPJ-GUESS and the TRENDY ensemble mean. The shaded area shows the model spread of the individual TRENDY models.

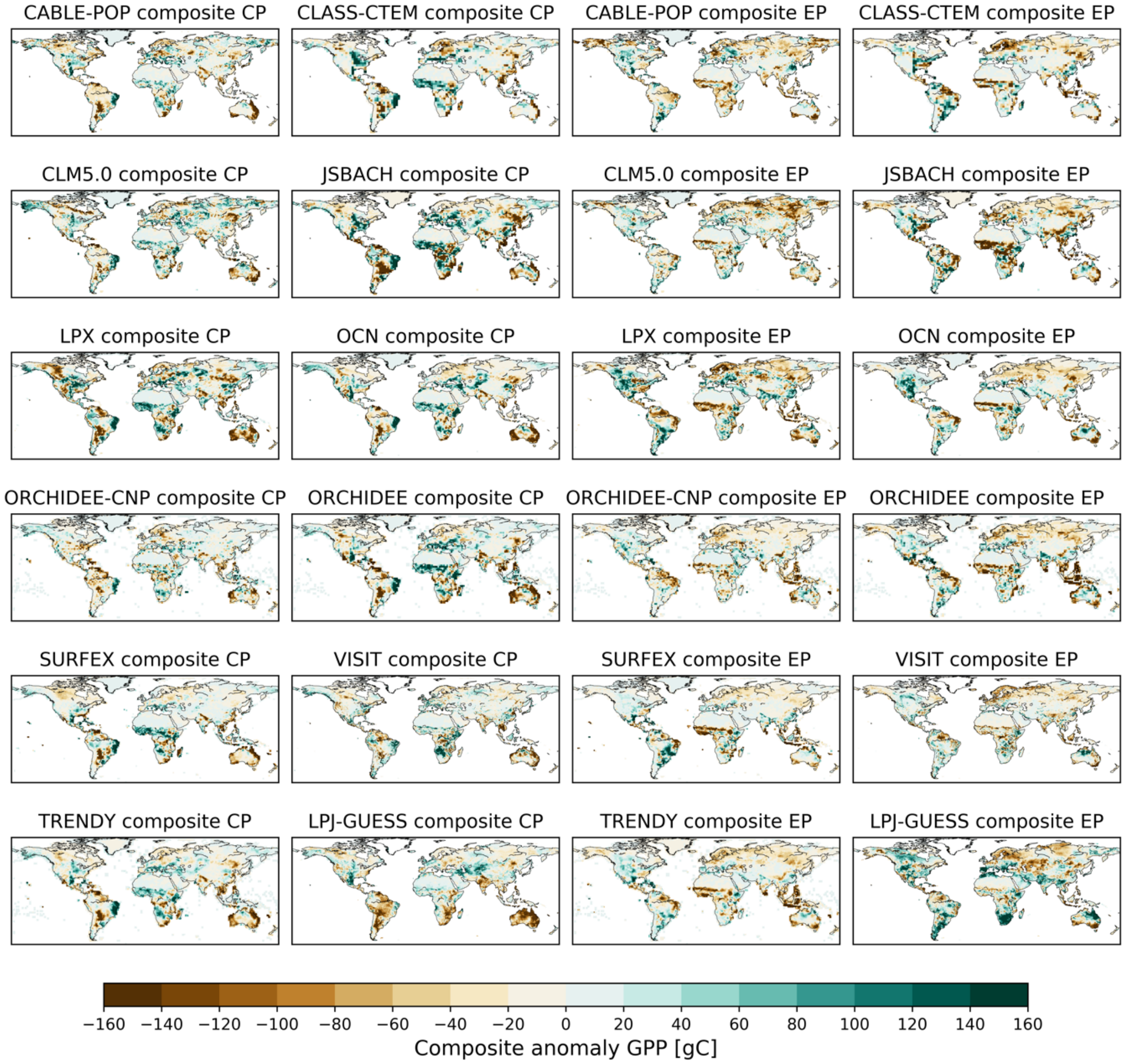

Fig. 2: Composite anomalies in gross primary production (GPP) summed over the the El Nino developing and decaying year for all CP and EP El Niño events listed in tab. B1 for the individual TRENDY models, the TRENDY composite and the individual LPJ–GUESS run (compare Wang et al., 2018).

Below we address the reviewer's comments point by point. We add our replies in italics and highlight suggested modifications in the manuscript in red.

Referee #3

1. Thank you for inviting me to review paper "Examining the sensitivity of the terrestrial carbon cycle to the expression of El Nino" by Teckentrup et al. First, may I apologise for taking longer than the expected four weeks to return the review. I realise it can be unfair on the authors to have the Comments section closed, and then another further review appears. For that reason, I have tried to make the review a "light touch", and predominantly suggestions for better framing of the analysis in the future work part. Possibly the most refreshing feature of this paper is that it actually has the confidence to present a "negative result". That is, for the processes investigated by factorial methods, these are likely to have a size that is relatively small compared to the overall impacts of on-going background climate change caused by fossil fuel burning. That is, though, still really important to know, and it does not diminish from the paper. However, by presenting the findings as unimportant also feels like a disservice to the paper findings? As so much recent research into the climate system illustrates, the simultaneous interannual variability of Earth System components does reveal much about potential long-term changes under global warming. Indeed the entire Emergent Constraint concept is based on such an approach. Hence, when placed in that context, the quite specific findings of this analysis become particularly important. I would encourage the authors to at least consider talking about this in the Future Directions part of the manuscript. When parts of ENSO are in a particular phase, what does it tell us about the terrestrial carbon store response, should general climate warming be in that state in a persistent way?

   We have thought about these comments carefully and would like to note that we mention the importance of different expressions of El Nino on interannual timescales of the terrestrial carbon cycle. We concluded that we could nuance our conclusions a little. We therefore adjusted our future directions:

   'Based on this analysis we suggest that our model sensitivity would likely be similar to that displayed by the other TRENDY models, although we would anticipate subtle regional differences, particular in the tropics if an alternative DGVM had been used'

   and conclusions:

   'Our results therefore suggest that the impact of different expressions of El Nino on the carbon cycle on long time scales is likely to be small.'

   to reflect some of this commentary by the reviewer.

   In the "Future Directions", the authors note that a more formal use of multiple DGVMs will help. The paper does not consider future projections, and it would certainly be interesting to see Figure 2d,e,f extended under the CMIP5/6 ensemble, maybe in a follow-on paper.

We agree that work that revisits this question for a future climate may well be warranted. Studies indicate changes in the properties of El Niño events, i.e. magnitude (e.g. Wang et al., 2019) as well as spatial features (e.g. Yeh et al., 2009). However, the representation of ENSO diversity in CMIP5 and CMIP6 models is associated with high uncertainty due to model biases especially in the equatorial Pacific, resulting in low model agreement (e.g. Freund et al., 2020). In order to get robust results, a future experiment set-up would need numerous climate forcing input datasets. In addition, we think that a future study would require multiple DGVMs since the results may be very sensitive to assumptions related to vegetation responses to [CO_2] and interactions with nutrients (Zaehle et al., 2014). We therefore viewed this as beyond the scope for this paper.

However, to reflect these comments by the reviewer we have added the following into the future directions text:

'Moreover, exploring the impact of different expressions of El Nino in a future climate would be worthwhile. However, we note that this would probably require multiple DGVMs to account for the uncertainty associated with the vegetation responses to [CO_2] and interactions with nutrients (Zaehle et al., 2014). In addition, the representation of ENSO diversity in CMIP5 and CMIP6 models is highly uncertain due to model biases, especially in the equatorial Pacific, resulting in low model agreement (e.g. Freund et al., 2020). Therefore, to obtain robust results, a future experiment design would require multiple climate forcing input datasets.'

2. Assessment of future findings will also have to be related to how well individual ESMs performing in projecting ENSO characteristics. The authors could also provide a couple of sentences on how others might be encouraged by this analysis to use data to assess the carbon cycle components of their analyses. Datasets do exist of the carbon cycle components, and for instance of NPP ("MODIS NPP"?). While some gridded datasets of terrestrial carbon do contain aspects of models in them e.g. to disaggregate from point to all locations, they still remain highly useful guides and are still "measurements" as such. What would comparisons show between the model-based findings of this paper and terrestrial carbon cycling measurements?

   We agree with the reviewer that it is useful to assess how well LPJ-GUESS simulates the terrestrial carbon cycle. We note that LPJ-GUESS is a well-established DGVM that has been evaluated against observations in previous studies (e.g. Smith et al., 2014). A previous study (Wang et al., 2018) found that the TRENDY models generally captured the anomalies in the terrestrial carbon cycle associated with different expressions of El Nino. We showed in the appendix figure B10 (or see above fig.1) that LPJ-GUESS lies within the uncertainty range of the TRENDY ensemble. The spatial distribution of the summed composite GPP anomalies (see fig. 2) further shows that LPJ-GUESS picks up the main features of anomalies associated with EP El Nino events (see fig. 2; compare TRENDY composite and individual models). The anomalies in GPP associated with CP El Nino events display generally weaker responses in Brazil and Western Africa compared to the ensemble mean and most individual models. This low sensitivity might also explain the relatively low correlation and R^2 values in figure 1 for tropical regions and may dampen the overall

response to the CP only scenario. We note however that LPJ-GUESS is still within the model range and can therefore be viewed as representative. In addition, LPJ-GUESS has a strong negative bias in Australia. As our results show, Australia does not make a large contribution to long-term changes in any of the carbon fluxes and pools. We therefore conclude that LPJ-GUESS was suitable to address our experiment.
We now include figure 2 in the manuscript and add in the future directions:

'The spatial distribution of the composite anomalies shows that LPJ-GUESS captures the features of anomalies in GPP associated with EP El Nino events compared to the individual models and the TRENDY model ensemble (see fig. B11). In contrast, LPJ-GUESS generally simulates weaker anomalies in GPP associated with CP El in Brazil and Western Africa compared to the ensemble mean and most individual models. This low sensitivity might also explain the relatively low correlation and R2 values in figure B10 for tropical regions and may dampen the overall response to the CP only scenario. We note however that LPJ-GUESS still is within the model range and can therefore be viewed as representative. In addition, LPJ-GUESS has a strong negative bias in Australia. As our results show, Australia does not make a large contribution to long-term changes in any of the carbon fluxes and pools.'

Finally, we argue that a comparison with satellite derived observations can only be helpful to a limited extend since, as the reviewer already mentions, satellite derived GPP or NPP products are based on light-use efficiency models themselves and therefore are not directly observed.

3. The authors could then discuss in a short paragraph how data can constrain which aspects of land surface responses are performing well, and where there are deficiencies. Once constrained, the implications under future climates can be characterised. Although ecosystem acclimation effects might have to be accounted for, this would still offer an extra way to use current interannual variability to tell us about climate impacts. That is the variations might tell us terrestrial carbon cycle response under a permanently adjusted near-surface climatic state.

   This is an attractive comment by the reviewer. Our results point to a lack of sensitivity of the simulated carbon cycle. Given the sensitivity is small, constraining elements of the response would tend to lead to an even smaller response. Therefore, this would not affect our conclusions.

4. This paper provides a framework of which ENSO" expressions" to focus on, on the path to constraining future projections of land carbon cycle change. The paper includes a particularly good introduction, and the broad literature search is undertaken well, capturing all the main recent papers on ENSO-Carbon cycle teleconnections. I am happy to see any new paper version, and I will try and return any further comments much more promptly.

   Thanks for your positive comments.

Small things

5. The word "expression" is used quite a bit e.g. in the discussion of the Central-Pacific and Eastern-Pacific features of El Nino. "Attributes" or "features" may be better words?

   The word 'expression' is different from 'attributes' and 'features'. We think it is probably the best word to use in this context, and it is a word others have used (for example, Tippett et al., 2020) in this context.

6. Can the diagrams could be tidied up a little more? To my eyes at least, some of the features of – for instance – Figure 2 are difficult to see. Slightly thicker curve linewidths might help, and without obscuring each other.

   We thank the reviewer for the suggestion and updated the figures accordingly.

7. A better use of the colourbars would help in Figure B1 for instance, to understand better the geographical spread. To achieve this could be by including colour steps that are not all of identical amounts. Clustering of some colour bounds more around the zero value will reveal more information in the maps?

   We thank the reviewer for the suggestion. The main point of our maps is to show that regional changes in the carbon fluxes and pools are small as well to further support that changes in the analysed variables might not be significant. We argue that a difference of -50 – 50 PgC for cumulative NBP over 45 years or for carbon pools is minor. Therefore, a more detailed representation would not lead to different conclusions.

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