Response to Reviewer #1

General comments

In their aptly titled 2024 article “Biogeochemical versus biogeophysical temperature effects of historical land-use change in CMIP6,” authors Amali et al. quantify the biogeophysical (BGP) and biogeochemical (BGC) effect of historical land-use change (LUC) as rendered in 13 earth system models of the sixth Coupled Model Intercomparison Project’s (CMIP6) Land Use Model Intercomparison (LUMIP) activity. Specifically, the authors seek to analyze the effects of historical LUC for carbon emissions and near-surface air temperature. Although the relative contributions of BGC and BGP effects of historical LUC have been studied using CMIP5 and Land-Use and Climate, Identification of Robust Impacts (LUCID) data, CMIP6’s LUMIP activity, prescribes a set of experiments to be carried out in common by modeling teams, using the latest generation of earth system models. The study is timely as the BGP impacts of LUC have often been overlooked. Where it has not been overlooked results have at times been difficult to interpret due to the variety of LUC schemes applied within CMIP5. This study avoids this particular challenge by using data from the latest generation of models and experiments where simulation protocols dictate greater consistency across models.

Two concentration-driven CMIP6 simulations are used by Amali et al. to analyze the effects of historical LUC. The *historical* simulation with LUC from 1850 to 2015 and *hist-noLu* where LUC is held constant from 1850. The difference between the two simulations is taken to determine the change in carbon storage and near-surface temperature. The authors use the TCRE to find the BGC temperature effect of LUC. To obtain gridcell depictions of this temperature effect, the authors use the regional-to-global ratio of temperature (or simple pattern scaling). These methods allow the authors to isolate the impact of historical LUC on the variables of interest and identify the contributions of BGC and BGP for each.

The study’s findings both align with and expand upon previous work. For example, the finding that near-surface temperature increase from BGC is greater than BGP for historical LUC aligns with the findings within the existing literature. However, the regional analysis in Amali et al. adds nuance to this story in that the regional effect of BGP on near-surface temperature can be significant depending on location. Also significant is the study’s contribution to our understanding of the BCG effect on near-surface temperature change at the gridcell level. Furthermore, the findings of this study demonstrates similar model spread and estimates to previous similar studies using LUCID or CMIP5 data, and identifies some reasons related to model architecture that contribute to this result.

This study is ambitious in scope, well-referenced, and contributes significantly to our understanding of the relative temperature contributions of the BGC and BGP effects of LUC, using a novel RGRT approach to do so. Its conclusions are supported by the results, however, it’s possible that the conclusion that both the local and non-local effects of LUC ought to be considered in climate policy development should be qualified, noting that this is because combined local and non-local BGP effects of LUC found in this study are not insignificant. The article is recommended for publication pending consideration of the questions and comments that follow.

Response: *Thank you very much for taking the time to review the manuscript thoroughly and for providing valuable feedback. We are glad for your positive and constructive evaluation of the manuscript, recognising its relevance, novelty, and well-referenced nature. In the following sections, we try to provide a point-wise response to the specific and technical comments raised.*

Specific comments

1. The abstract provides a complete and concise summary.
2. The manuscript is also well-structured in that the sections and subsections allow the authors to present their methods, results, and discussion in a manner that is both logical and appealing from a reading flow perspective. One subsection that might benefit from being split in two is 2.3.2, where “Global temperature response” and “Local contributions to global temperature change” could each be their own sub-sections.

   Response: *Thank you for pointing this out. We have now restructured the manuscript following your suggestion. The revised structure of the subsections now reads,*

   2.3.2: Global temperature response
   2.3.3: Local contributions to global temperature change
   2.3.4: Descriptive Statistics

3. The figures do a good job of presenting the results and key points for discussion in a readable fashion. Related to the methods and the results presented in Figure 3 where *ΔTbgc* is presented, why is there no test of statistical significance as is the case for *ΔTbgp*?

   Response: *Thank you for pointing this out. We have now conducted a 1-sample t-test on the 1pctCO2 simulation. For the multi-model mean ΔT_{bgc} (Fig. 3), stippling indicates regions where 2/3 of the models are not statistically significant at the 95% confidence level. We have added this information to Fig. 3a. The result of the individual models is shown in the figure below, which we have now updated for Figure S6. We have also updated the methods section to reflect this.*

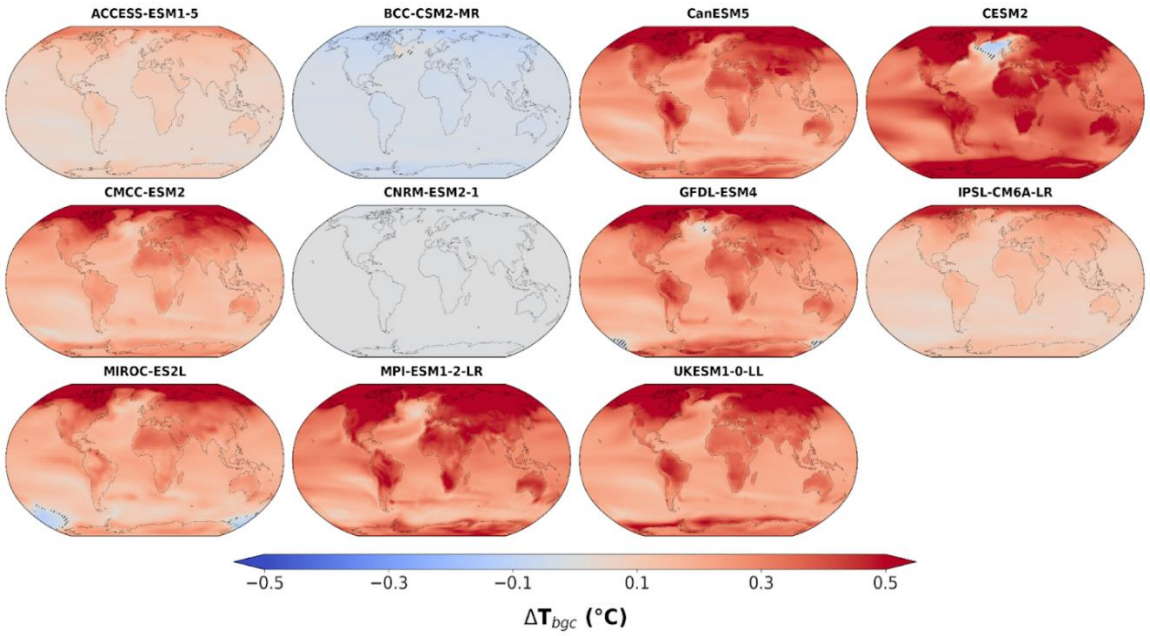

Figure S6: *Temperature response to land-use-induced CO2 fluxes. Results computed from Equations 2 and 3 using global mean land-use CO2 emissions (1985 – 2014), global mean temperature from 1pctCO2 simulation, and TCRE values derived in Arora et al. (2020) and Lovato et al. (2022). Stippling indicates regions that are not statistically significant at the 95% confidence level.*

4. The methods are clearly described, including useful model information presented in tabular form and details of the statistical analysis. Related to the latter, is it possible to include which type of interpolation method was used to bring all of the simulation data into a common grid? This would aid with reproducibility.

   Response: *Thank you for highlighting the need for reproducibility. In the ending statement of section 2.3.4 (formerly section 2.3.3) we mentioned that "For spatial representations, we interpolated the results of each model using the Climate Data Operator (CDO; Schulzweida, 2023) onto a uniform grid, using a spatial resolution already common to some of the ESMs: 0.94° x 1.25° (latitude x longitude). For extensive variables, such as land-use emission, we used conservative remapping with the `remapcon` function to preserve the integrals of the global totals (Jones, 1999). For intensive variables, such as temperature, we used bilinear interpolation with the `remapbil` function to preserve the mean values." We believe this clarifies the concern of the reviewer.*

5. Related to Table 2, is it possible that the average ΔcLand is -131.9 (±96) GtC rather than -122 (±96) GtC?

   Response: *Thank you for noticing this. Yes, indeed. But in the caption of Table 2, an excerpt reads "[...] The model marked * (EC-Earth3-Veg*) is excluded from the multi-model mean of ΔcLand because it has no fully activated carbon cycle." If this model was included, the multi-model mean of ΔcLand would indeed be -131.9 (±96) GtC. But we excluded it from our computation due to the reason earlier given, resulting in a ΔcLand value of -122 GtC.*

6. On page 14 where the methods for obtaining the grid cell temperature contribution and effect are discussed, is it possible to add a small amount of text to indicate the significance of or motivation for providing both quantities?

   Response: *Thank you for pointing this out. Following your suggestion, the new section 2.3.3. now reads, "We further attempt to distinguish between the grid cell temperature contribution and the grid cell temperature effect. The temperature contribution quantifies how much an individual grid cell's LUC adds to the global temperature signal, highlighting the locations that contribute most significantly to the global pattern. In contrast, the temperature effect measures how the climate in each specific location (grid-cell) is affected by global LUC, allowing us to assess localised impacts. Providing both quantities thus enables us to understand both the aggregate impact of LUC on global temperature and the specific local climate response to global LUC" The sentence in blue has been added to make our motivation more explicit.*

7. Page 25 line 511: "In magnitude, the warming pattern around Greenland can only be seen in the BGP contribution, which we attribute to mechanistic non-local LUC-induced effects on ocean currents and sea ice." This result seems worthy of mention in the discussion and conclusion sections.

   Response: *Thank you for highlighting this aspect of our research. We have now included this in the*

   Discussion: "[…], the poleward warming contribution is due to the BGP effect alone, which includes both the local and non-local effects of LUC. For example, the warming pattern around Greenland seen only in the BGP contribution (Fig. 6c), can be attributed to mechanistic non-local LUC-induced effects on ocean currents and sea ice." and

   Conclusion: "[…] we find warming contributions over regions such as eastern Canada,

central Australia, and the tropics. We identified the warming contribution over the tropics resulting from the BGP effects as the only commonality between the BGP and BGC effects. In contrast, the warming pattern around Greenland can only be seen in the BGP contribution, which we attribute to mechanistic non-local LUC-induced effects on ocean currents and sea ice."

8. Page 28 line 550: Is it possible to include the direction in which AMOC may have been influenced?

   Response: *We appreciate your interest in the potential influence of AMOC on the spatial patterns observed in our results. While we acknowledge that these patterns may suggest links to changes in simulated AMOC strength, a detailed analysis of AMOC behaviour is beyond the scope of our current study, which focuses primarily on the biogeophysical, and biogeochemical impacts of historical land-use change on near-surface air temperature and carbon dynamics.*

   That said, we have included the statement […] namely Arctic and Antarctic sea-ice, and may have influenced the Atlantic meridional overturning circulation (AMOC) "The spatial temperature patterns in some models, particularly in higher latitudes, suggest links to AMOC changes. This interpretation aligns with findings in the broader literature, such as Weijer et al. (2020) (https://doi.org/10.1029/2019GL086075), which discusses AMOC behaviour in CMIP6 models, and other studies examining AMOC fingerprints (e.g., Rahmstorf 2024, https://doi.org/10.5670/oceanog.2024.501)". We suggest these references for further insights into AMOC-related changes in CMIP6 models and their implications for regional climate patterns.

9. For the subplots in Figures 2-4 that represent just the direction of change and not the magnitude, is it possible to remove the numbers from the colorbars?

   Response: *Thank you for your suggestions. However, on closer review, we think the numbers below the colour bars help in identifying the number of models that agree on the direction of the signal. We have therefore modified the label to read "Number of Models" and added a statement in the figure caption that reads "[...] indicating the number of ESMs that agree on the direction of the signal."*

Technical corrections

1. Page 5 line 119: Please delete the "s" at the end of "backdrop."

   Response: *Right, we removed the "s".*

2. Page 13 line 313: The text reads "for a period ranging between 150 to 165." Please include the unit for "150 to 165" if units apply.

   Response: *Thank you for pointing this out. This has now been modified to "150 to 165 years"*

3. Page 17 line 403: In "- a trend" [...] "ΔcSoil -," please replace the hyphens with em-dashes.

   Response: *Thank you for spotting this. The hyphen has been replaced with em-dashes and we also checked the entire manuscript for similar occurrences*.

4. Page 24: The acronyms given in the caption for Figure 5 are not consistent with those given in the figure and in some places in the main text. Please adjust.

Response: *Thank you for pointing this out. The acronyms used in the figure caption have been modified to reflect those provided in the figure as well as in other places in the main text. For example, the Figure 5 caption now reads "The acronyms are NAT = North Atlantic, NAM = North America, EUR = Eurasia, SEB = South East Brazil, WAF = West Africa, SEA = Southeast Asia."*

5. Page 27 line 543: In the sense that is likely intended, "widespread" ought to be written as "wide spread."

   Response: *Thank you for spotting this. The phrase has been changed from "widespread" to "wide spread"*

6. Page 29: For Figure 7, is it possible to replace the dashed line separating the temperature (panels a and b) and carbon stock (panel c) with a solid line? This might further emphasize that data on two effects are presented in this figure.

   Response: *Thank you for your suggestion. The dashed line has been replaced with a simple line and the figure has been modified also in line with other comments received. The new Figure 7 is shown below*

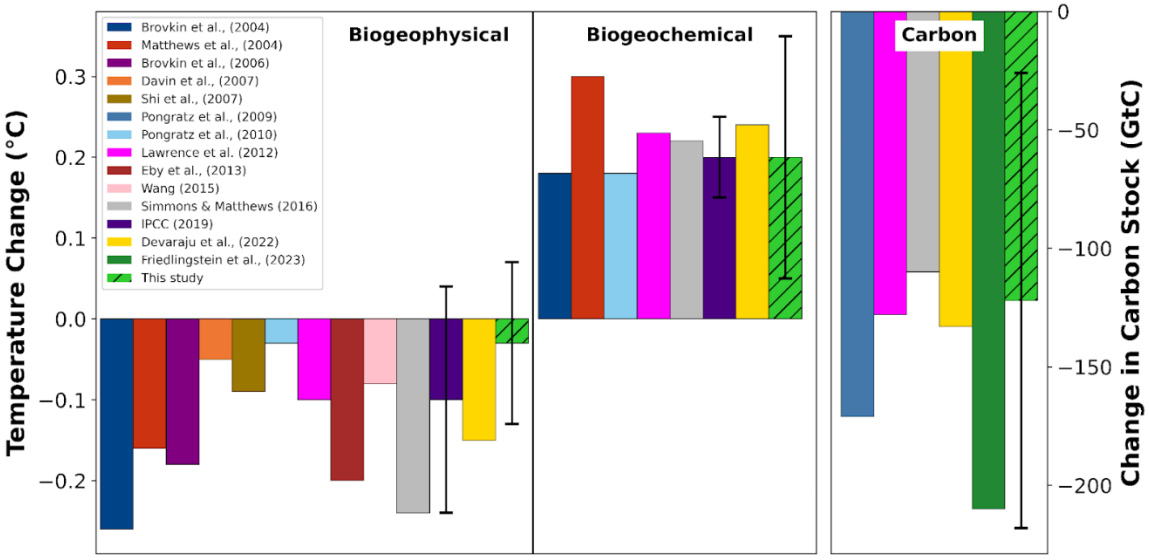

Figure 7. Biogeophysical, biogeochemical effects, and changes in carbon stocks quantified in this study (hatched green bars) compared with other studies. Where vertical lines exist, they represent the standard deviation of estimates. See Supplementary Table S2 for the studies and their estimation periods.

7. Page 30 line 609: Should "BGC and BGC" read "BGC and BGP"? If so, please change this.

   Response: *Yes, thank you for spotting this. This has been corrected and the statement now reads "[…] we show the aggregate of the BGC and BGP effects […]"*

8. Page 36 line 791: Is it possible that temperature is being referred to here rather than "climate"?

   Response: *Thank you for bringing this to our attention. We revised this and the sentence now reads "In this study, we primarily focused on separating the temperature response caused by biogeophysical (BGP) effects of historical land-use change (LUC) from those caused by biogeochemical (BGC) effects. We go beyond previous studies to analyse the*

most recent CMIP6 data, using state-of-the-art datasets contributed by the LUMIP project in an attempt to improve existing knowledge on the relative contribution of BGP and BGC effects of LUC on the "climate". However, we use the term "climate" here to collectively refer to effects beyond temperature alone.

9. The supplementary information is very helpful for understanding the results model-by-model. It's possible that colorbars in figures S13, S14, S15, and S16 are a bit high compared to previous multi-model plots in the supplement

   Response: *Indeed, the values in the colorbars of Figures S13 - S16 are high compared to the multi-model plots because they are in a different unit [%]. Here we show the percentage change across different land cover types*

References

Jones, P. W. (1999). First- and Second-Order Conservative Remapping Schemes for Grids in Spherical Coordinates. Monthly Weather Review, 127(9), 2204–2210. https://doi.org/10.1175/1520-0493(1999)127<2204:FASOCR>2.0.CO;2

Rahmstorf, S. 2024. Is the Atlantic overturning circulation approaching a tipping point? Oceanography 37(3):16–29, https://doi.org/10.5670/oceanog.2024.501

Weijer, W., Cheng, W., Garuba, O.A., Hu, A., Nadiga, B.T. (2020) CMIP6 Models Predict Significant 21st Century Decline of the Atlantic Meridional Overturning Circulation. Geophysical Research Letters, 47(12): 47, https://doi.org/10.1029/2019GL086075