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Interactive comment on "Earth system feedbacks following large-scale tropical forest restoration" *by* Alexander Koch et al.

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We thank reviewer 1 for their detailed comments and suggestions. Our replies (standard font) to the primary comments (italics) are below. We have addressed the handwritten comments directly in the manuscript.

1. *In context of the terminology, I have two primary comments. First, I find the use of the term "control" to describe the RCP 2.6 scenario somewhat confusing. In the climate and Earth system modelling literature the term "control" is typically used for the preindustrial simulation. I suggest calling the standard RCP 2.6 simulation what it is - the RCP 2.6 scenario. Second, I am confused by the term "restoration". I am familiar with the terms reforestation, deforestation, and afforestation but I have no idea what*

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does the term "restoration" actually refers to. I understand the intent here but perhaps it would be helpful to clarify the intent more clearly and upfront in the manuscript.

We have renamed the "control" RCP 2.6 scenario simulation to "esmrcp26", highlighting its similarity to the emission-driven CMIP5 "esmrcp85" experiment (https://view.es-doc.org/?renderMethod=id&project=CMIP5&id=b933ca20-d3a5-11df-837f-00163e9152a5) to avoid confusion with the standard concentration-driven "rcp26" experiment. We also changed the name of the restoration simulation to "esm-rcp26restor". The term "forest restoration" is used in forest ecology to describe actions that lead to the recovery of forests, their biomass, biodiversity, or other ecosystem services (e.g. Lamb et al., 2005). In its simplest form this can be achieved by abandoning land use and letting vegetation regrow. This is exactly how our restoration experiment works, all land use activity in the tropics is ceased and natural vegetation is allowed to regrow.

We have now added a definition of forest restoration in line 26.

2. *Why the emissions driven RCP 2.6 scenario in this manuscript is driven with diagnosed emissions from the concentration driven RCP 2.6 scenario simulation of the HadGEM2-ES. Wouldn't it had been much easier to explain and to drive the emissions driven simulations of the RCP 2.6 scenario with the standard emissions provided by the integrated assessment models for the RCP 2.6 scenario.*

Jones et al. (2013) have shown that HadGEM2-ES achieves the decline in atmospheric CO2 concentrations as specified in RCP 2.6 without the need of negative emissions. This means that when driven by RCP 2.6 emissions HadGEM2-ES would simulate lower atmospheric CO2 concentrations than specified in RCP 2.6. We have therefore decided to use the fossil fuel emissions that match the RCP 2.6 atmospheric CO2 concentrations.

We have now added a brief explanation in line 96.

3. *I am unclear of the protocol followed in the "restore" simulation. The reason for this is that the manuscript doesn't show time series of crop [and pasture] area in the "control" and "restore" simulation so I can't visualize how anthropogenic LUC is avoided in the "restore" simulation. This, I think, is the first aspect. The second aspect is related to the fact that the TRIFFID component of the MOSES land surface scheme is able to simulate the fractional cover of its plant functional types (PFTs) dynamically (note that I am not calling it "dynamic vegetation"). I am unclear how this second aspect works. Is the model allowed to dynamically simulate fractional cover of PFTs in areas already deforested and is this the reason for expansion of trees into an area of 1529 Mha?*

The grey line in Figure 1A denotes anthropogenic disturbance (i.e. crops and pasture). We have now changed the label to "Crops + Pasture". The reviewer's assumption is correct, the model dynamically simulates the fractional share of each PFT based on a plant competition (Lotka-Volterra) approach where trees outcompete shrubs and woody vegetation outcompetes grasses under suitable climatic conditions. Land use is simulated by applying a mask where no trees are allowed to grow, and existing trees are being replaced with bare soil (which in turn will be replaced by C3 and C4 grasses, representing crops and pastures over time).

We have now changed Figure 1a's legend from "disturbance" to "Crops + Pasture" to highlight the type of anthropogenic land use and adjusted the figure caption to emphasize that the anthropogenic land use mask converts to crops and pasture. We have changed anthropogenic disturbance to anthropogenic land use where suitable in the text. We have clarified that TRIFFID simulates the fractional cover of each PFT dynamically in line 70ff.

4. *I have no clue what is the purpose of section 1.3. I was not able to understand the context for this section and it appears to come of the blue.*

Section 1.3 describes the biomass scaling we discussed in section 4.1 (now section 5.1) and was accidentally left in this place from an earlier version of the manuscript. It has now been placed in section 5.1 “Restoration timescales and carbon uptake”, line 316 where more context is provided . We apologize for this mistake.

5. *At a number of places in the manuscript, it is mentioned that the carbon not released by avoided deforestation and carbon sequestered by the expansion of tree cover does not yield the expected reduction in atmospheric CO2 burden because this carbon benefit is overwhelmed by negative feedbacks. These negative feedbacks include reduction in CO2 uptake by the ocean and extra-tropical vegetation due to the reduction in atmospheric CO2 concentration.*

In the context of the earth system, positive and negative feedbacks amplify and reduce the initial perturbation, respectively. For example, the carbon uptake by land and ocean in response to increasing atmospheric CO2 is a negative feedback since it reduces the amount of CO2 in the atmosphere caused by fossil fuel emissions. If we use this standard definition/sign/interpretation of feedbacks then it becomes a little difficult to interpret that the negative feedbacks as you call them in your study reduce the climate benefit of “restoration” since in the normal context of climate warming negative feedbacks are the good feedbacks that reduce the rate of climate warming.

Perhaps it would be more clear if the phrase “negative feedbacks” is not used in this context but rather it is explicitly mentioned that “the carbon benefits of avoided deforestation and the increase in forest cover, in the restore simulation, are not fully realized because the resulting reduction in atmospheric CO2 also reduces carbon uptake by the ocean and extra-tropical forests”.

We agree with the reviewer and changed all instances where we use the term “negative feedback” accordingly. Line 228 – changed to “reduced uptake by the ocean” Line 341 – changed to “reductions in carbon uptake by the ocean and extra-tropical forests” Line 412 – changed to “carbon benefits of avoided deforestation and the increase in forest cover are not fully realized because the resulting reduction in atmospheric CO2 also reduces carbon uptake by the ocean and extra-tropical forests”

6. *Equation (1) on page 4 is not 100% correct. The reason for this is the ambiguity in the term E DEF OR which represents the deforested biomass according to lines 72 – 73 on page 3. Note that the deforested biomass is allocated to wood product pools with different turnover timescales. As a result, the land-use change related emissions seen by the atmosphere (and thus in equation 1) are not equal to deforested biomass but rather the sum of the fluxes from the wood product pools. Please note and correct this subtlety when revising your manuscript.*

We have now adjusted the description of EDEFOR in line 78 to highlight that it represents the emissions into the atmosphere from sum of the wood product fluxes at a given point in time. We use EDEFOR instead of ELU to emphasize that emissions from land use calculated in HadGEM2-ES only include deforestation emissions.

7. *There are two aspects to vegetation acting as a dynamic component in an Earth system modelling framework. The first is related to changes in the structure of the vegetation including vegetation height, its leaf area index, rooting depth, prognostic leaf onset and offset times and its biomass. These dynamic changes in vegetation structure, in response to changes in climate and atmospheric CO2 concentration, occur regardless of changes in the spatial extent of vegetation. The second aspect of vegetation dynamics is related to the changes in the fractional coverage of different PFTs. In the manuscript, the term "dynamic vegetation" is used to describe the second aspect. I would suggest to be explicit here (as I have done in point 3 above) and clearly mention "the changes in the spatial extent of PFTs" if that's what you're referring to.*

We thank the reviewer for pointing this out. TRIFFID is a dynamic vegetation model that simulates changes in the fractional coverage of the PFTs dynamically. We have now clarified this in lines 71ff.

8. *Lines 356 – 357. You cannot call HadGEM2-ES the most sophisticated ESM. The diversity of ESMs in the climate community is considered a healthy aspect of the community. Several studies have shown that the model mean response to any perturbation*

is more robust than any individual model.

Absolutely, by no means were we attempting a rating of individual models. We were referring to the model and scenario choice so far used for such an experiment since previous models are all pre-CMIP5 generation models forced with high CO2 concentrations and/or fully afforested/deforested scenarios. We have now changed the wording to “more recent ESM and scenario choice”.

9. *Finally, I think the manuscript can benefit from some reorganization to improve the flow of the manuscript. Perhaps starting with the big picture of changes in atmospheric CO2 burden and temperature, followed by land C changes, and then finally by ocean C changes will be helpful.*

We thank the reviewer for the suggestion. We think that showing the i) impact of the cessation of tropical land use and the subsequent land cover change, ii) its impact on terrestrial carbon and then iii) the global response to that makes it easier for the reader to follow.

Regarding co-authorship, we closely worked with the relevant Earth System Modelling team at the Met Office and are grateful for their support as stated in the acknowledgement.

Minor comments from handwritten notes

line 96 reformat equation and introduce terms We thank the reviewer for this suggestion. We have reformatted equation 1 and are now introducing the terms.

Figure 1A legend labels; y-axis in % We have changed the figure labels to be more informative. The aim of Figure 1A is to illustrates the trajectory of the PFTs over time. Table A1 contains the information of the absolute area change by 2100.

line 121 is this global change in the area of BDL trees over 2008-2100? This is the global difference between emsrcp26restor and esmrcp26, although most of this is due to increases in BDL in the tropics (see Table A1). We have highlighted that this differ-

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ence is between emsrcp26restor and esmrcp26.

line 125 how about plots to confirm this We have now added Figure A2 and reference it here.

Use million km2 or km2 instead of Mha Several studies and initiatives addressing forest restoration work in million ha (Mha). We therefore keep these units but provide a conversion in the caption of table A1.

In RESTORE is future LUC stopped in addition to making additional deforested area available for tree growth? That is correct, we have now clarified this in line 48 and again in line 117.

Line 148 show decline in NPP in Figure The time series of NPP can be found in Figure A3A. We have now added a reference.

Put thick moving average line in Figure 3 Adding a moving average would blur the abrupt changes we see in e.g. Figure 3C. We don't think any additional information would be conveyed by adding a moving average here.

Does delta SC also contain changes in the litter pool? HadGEM2-ES does not have a litter pool, carbon from litter fall is directly moved to a fast, medium and slow soil carbon pool. We thank the reviewer for highlighting this and have added this information in line 89ff.

Issues with figure labels line 230ff We have now corrected the figure references and apologize for the confusion.

Is FA a flux or is it the atmospheric C burden? FA is net carbon flux into the atmosphere (line 242).

Figure 4 change y axis and increase size of legend Done.

Line 243 Do you mean planetary albedo due to reducing snow and sea ice. Yes, although we prefer the term surface albedo here to emphasize the surface changes.

We do not make any assumptions about snow or sea ice cover as this is beyond the scope of the manuscript.

Line 245 Only someone who is familiar with literature may understand what a 5%, 2.62 W/m2 decrease in albedo means. The follow-on sentence describes that the lower surface albedo has a warming effect. We believe this sufficiently explains what a 5

Line 319 How were these numbers calculated with restoration simulation alone? The carbon benefit on a per area basis from stopping deforestation is calculated using the difference between esmrcp26restor and esmrcp26 for EDEFOR and RCP 2.6 land use change over 2008-2100 (9.6 Pg C / 286 Mha). Similarly for the forest restoration we use the difference between esmrcp26restor and esmrcp26 for FLA and the abandoned 2008 land use area (41.8 / 1529 Mha). We have added this to the per area numbers.

Line 394 You haven't paid any specific attention to negative emissions as such. Just that your restoration is based on a scenario which happens to have negative emissions. We highlight the response of the Earth System to negative emissions, i) the reduction in land and ocean carbon uptake after the reduction of atmospheric CO2 through negative emissions and ii) that the Earth System response to these negative emissions reduces their carbon benefit by more than 50

Sources: Lamb, D., Erskine, P. D., and Parrotta, J. A.: Restoration of Degraded Tropical Forest Landscapes, Science (80)., 310, 1628–1632, 2005.

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