The biogeophysical effects of idealized land cover and land management changes in earth system models

Response to reviewers

13/04/2023

We would like to thank all reviewers for their dedicated time reviewing the manuscript and for their useful and constructive suggestions. We especially thank reviewer 2 for highlighting mistakes and misinterpretation related to different modelling philosophies of EC-EARTH compared to the other two ESMs. We believe the review phase has greatly benefitted the scientific quality of the manuscript. As reviewer 1 did not have any additional comments we focus on the comments of reviewer 2 here.

Reviewer 2 Comment 1
L126 Update Döscher et al. to the published article.

Response

We thank the reviewer for pointing this out, the manuscript now refers to the published article.

Reviewer 2 Comment 2

L186-195 This is not totally true. EC-Earth has a dynamic vegetation model (LPJ-GUESS, Smith et al. 2014) and this is different from CESM and MPI-ESM. The main difference is in the assumption of what a forest is. For CESM and MPI-ESM the areas that are afforested are assumed to be a forest directly (in a physical sense) despite that the tree PFTs don't have any biomass. The forest just appears directly after the land cover map is changed. This is an assumption/model setup that you can have, but why this was made differently for EC-Earth I don't understand. In the EC-Earth setup of this study, it is the biomass of the trees that determines the physical parameters of the forest which is the opposite of the other models. It will take time for a tree to grow to a size that affects anything. And perhaps in many of the areas where the forest should be, the tree PFTs might not be productive and no tree biomass is created. I guess that the tree biomass between the three models is similar in areas of afforestation but definitely, the physical parameters are different due to the differences in model setups. This difference in the setup is what drives the difference between the models, not that EC-Earth has a dynamic vegetation model. To state that the same approach isn't possible for EC-Earth (having a physical forest directly after the change of land cover map) is not true. There is no switch for this, but a very small hack of the code would make the EC-Earth behave in the same way as CESM and MPI-ESM. It is pity that this hasn't been done as now any FRST-CTRL comparison between the models is extremely hard. This also explains the albedo discrepancy or EC-Earth compared to the other models in Figure 4c and D2 and makes your statement in **L778-783** wrong. There isn't an error in how EC-Earth represents albedo, but an error in your model setup, as explained above. If there isn't any extensive new tree biomass in afforested areas, then you won't see a change in albedo. The other models see a change in albedo due to the physical parameters being set to be a forest, hence they see a large change in albedo. This discrepancy between the model setups needs to be made very clear, as the author seems to not understand it themselves and make wrong statements about EC-Earth due to their error in setting up the model simulations. Also, all other FRST-CTRL comparisons with EC-Earth show very small effects. This is also due to the above-explained setup error. And FRST-CROP comparisons with EC-Earth will mainly be driven by the CROP change to CTRL as FRST to CTRL shows so minor differences. So the effect of the different model setups needs to be made much clearer.

Response

We thank the reviewer for there comment and clear explanation. This simulation setup was chosen as we were not aware of the possibility of a workaround to prevent dynamic vegetation within EC-EARTH which would allow us to force this model with prescribed land cover maps. If we would have been aware of this option we would have definitely chosen for this option as this would indeed improve comparability of the FRST simulation. We agree with the reviewer that this should be made more explicit within the manuscript. The link to the issue of lack of local albedo was indeed not interpreted as such but we thank the reviewer for clearly highlighting this here. In the revised version of the manuscript we have included several clarifications and added these here below, the altered parts are indicated in blue. In the last paragraph of methods section 2.1.1 where the ESMs are presented we made this difference in assumptions explicit:

> There are some important differences in how the different ESMs treat land cover. They have a different amount of PFTs which are also defined in different categories. Moreover while in MPI-ESM and CESM land cover is handled within one single sub-model (their respective land surface schemes JSBACH and CLM) and is prescribed, in EC-EARTH there are different models for vegetation dynamics and biogeochemistry (LPJ-GUESS) and for the water and energy cycle (HTESSEL). This implies that for CESM and MPI-ESM the areas which are afforested are assumed to be a physical forest immediately. This is in contrast to EC-EARTH where the dynamic vegetation model determines the physical properties of trees from biomass buildup through vegetation growth.

Next we highlighted this again in the results section within the ‘Evaluation of biogeophysical response to deforestation’ section (section 3.1) where we make the link with our simulation setup and lack of local albedo explicit:

> In EC-EARTH the local albedo change is zero (Figure 4c), however there is a stronger non-local albedo ~~change despite this being almost absent in other ESMs~~ (Figure D1). The non-local albedo change is near-zero except over boreal latitudes~~, where it agrees in sign with observations but strongly underestimates the magnitude~~ (Figure D2). This could be caused by the differences in simulation setup for EC-EARTH where forest needs to establish throughout the simulation while in CESM and MPI-ESM these are immediately established. This albedo bias due to differences in simulation setup likely explains the lack of cooling in boreal latitudes for this ESM (Figure ~~D2~~ 3).

This link to simulation setup and lack of albedo changes in EC-EARTH is further highlighted in Appendix D which has been largely rewritten to further explain that the lock of forest growth is the reason for the lack of local albedo in EC-EARTH:

> This is further illustrated by Figure D2 where the latitudinal averages of the local, non-local and total effects are compared to the observational datasets from Duveiller et al. (2020) and Li et al. (2015). This again illustrates what was mentioned above, i.e. there is no local component of albedo change for EC-EARTH while this is the dominant component for MPI-ESM and CESM. However it also clearly shows that even when total effects are considered EC-EARTH strongly underestimates albedo change compared to the observational datasets. This is especially important in the boreal latitudes where EC-EARTH does show a slight increase in the NH, however this effect is still less than half as strong as the observational datasets indicate. ~~Moreover it should be noted that the non-local effects of CESM (which is likely an effect from additional snow due to the non-local cooling, see Figure C3 shows a gradual increase towards the poles, the non-local effect in~~ Due to the specific simulation setup used in this study EC-EARTH ~~in contrast shows a very similar shape to both the local effects from~~ is not able to grow sufficient amounts of vegetation to cause a clear local albedo effect, only non-local effects are visible for this ESM. In CESM and MPI-ESM ~~as well as the observational datasets. This indicates that the non-local effect in EC-EARTH is related to the areas which~~

> ~~have undergone~~ this issue does not occur as the land cover change ~~in contrast to CESM where it is more related to the latitude and snow cover.~~ Immediately implements a physical forest without the need for these to grow.
>
> It should be noted that due to this issue, EC-EARTH has undergone less land cover change in the CROP-FRST case compared to the other ESMs as the FRST simulation for this ESM showed very little afforestation amounts (see Figure 1)~~, which likely explains the underestimation of the total albedo effects for this ESM. However, it remains clear that EC-EARTH has an issue in how the effects on albedo as a consequence to land cover changes is modelled as this should be local by design. This issue should be taken into account within the future development of this ESM as albedo is a crucial variable to understand the effects of land cover changes on the climate.~~ and these forests are only established to a limited extent causing smaller biophysical effects on the atmosphere.

Next, we repeat this explicitly in the first section of the discussion when highlighting some inconsistencies across the ESMs (section 4.1):

> Although we have harmonised the land cover and management representation across the different models, strong differences remain, most notably in the implementation of irrigation expansion and afforestation (Figure 1). This implies that the comparison of the different simulations across ESMs is not perfect and inconsistencies can be caused by disparity in model structure and by spatial differences and differences in extent and implementation of the applied LCLMC. As for afforestation, the differences found here were mainly caused by the ~~technical difficulty of implementing this in the dynamic vegetation model LPJ-GUESS used in EC-EARTH.~~ differences of implementation of forests in EC-EARTH (which grows them throughout the simulation) compared to CESM and MPI-ESM which start of with a physical forest.

Finally, we explicitly state the possibility of forcing EC-EARTH to behave like CESM and MPI-ESM (by prescribing land cover) within the last section of the discussion regarding Limitations and Future Outlook (section 4.4):

> The afforestation implemented in ~~For~~ EC-EARTH~~, even though it has a highly advanced land model (LPJ-GUESS), the interface with the atmosphere is handled by a more simple submodel (HTESSEL) within the atmosphere model IFS. This causes some clear biases such as the unrealistic partition of albedo as a non-local feature in EC-EARTH (Figure 4c). Addressing these biases could be a useful strategy when further developing this ESM to make land cover induced climate effects more realistic.~~ in this study could have been improved and made more comparable to the other ESMs by changing the simulation setup. For example by forcing forest to exist from the start of the simulation (as was done in MPI-ESM and CESM) in stead of allowing EC-EARTH to model afforestation as default within the dynamic vegetation model LPJ-GUESS (i.e. growing trees from seedlings).

Reviewer 2 Comment 3

L197-202 The irrigation in EC-Earth is only applied to the dynamic vegetation model. The physical model (IFS/HTESSEL) doesn't see any difference between an irrigated or rainfed cropland as it has a separate water cycle compared to LPJ-GUESS (see Döscher et al. 2022). So, no water is added to the physical model. The only difference it sees is the change in LAI between an irrigated and rainfed crop PFT. This needs to be explained as this makes it easier to explain the small temperature impact in Figure 7i-l. It is too late to bring this up in the discussion (**L639-642**), it should be explained already when the experimental design is described and hence EC-Earth should be fully excluded from the IRR-CROP analysis as has been done in figures 9 and 10.

Response

We thank the reviewer for highlighting this aspect and we agree that this lack of communication between the atmosphere and dynamic vegetation components is important to clearly state early in the manuscript. However, this is already highlighted in the manuscript at several occasions in the current version of the manuscript as shown below:

Appendix B explicitly states this issue regarding EC-EARTH and the appendix is referenced in methods section 2.1.2:

> Although the individual implementations of the irrigation parameterisation differ, all models follow a similar logic. Once a crop suffers a certain amount of water stress (defined differently in the models, see Appendix B), this amount is replenished by applying an irrigation flux until the water stress is relieved

Second this is mentioned in the description of the irrigation induced temperature results shown in Figure 7 in the first paragraph of section 3.2.3:

> In the idealised irrigation expansion sensitivity experiment (IRR-CROP, i.e. irrigation expansion in a full cropland world), both MPI-ESM and CESM agree on the irrigation-induced reduction in local surface temperature, while irrigation expansion in EC-EARTH does not induce any local effects (Figure 7). The very limited local effects in EC-EARTH are caused by a lack of moisture exchange between IFS and LPJ-GUESS, whereby water added in LPJ-GUESS for irrigation does not affect the moisture fluxes in IFS. Hence, in EC-EARTH, irrigation affects crop growth and albedo but does not alter turbulent surface fluxes.

However as it is clear from the reviewers comment that this should be brought forward more clearly we also added an explanation of this issue explicitly in the last paragraph of methods Section 2.1.2 regarding the experimental setup:

> Note that within EC-EARTH, irrigation is implemented in the dynamic vegetation model LPJ-GUESS but not within the atmosphere model IFS (due to both models having a separate water cycle). Therefore climate effects within this ESM from irrigation expansion can only occur due to greening of plants (Döscher et al., 2022).

Additionally we made it more explicit in the discussion in order to highlight that the irrigation induced climate effects are only caused by greening due to increased water availability:

For irrigation expansion, MPI-ESM and CESM consistently show that the increase in latent heat dominates the surface temperature response, causing a local cooling. In EC-EARTH, the moisture fluxes to the atmosphere caused by irrigation are not modelled, hence the only effect is due to greening of crops which is more limited.

We would still argue that the EC-EARTH results of IRR-CROP (fig 7) are useful to be shown despite knowing in advance that these climate effects will be minor due to the lack of communication of the water flux between the atmosphere and vegetation dynamics model. As there are still climate effects modelled in the greening of crops in this ESM. Furthermore, it clearly illustrates the importance of modelling this water flux in order to simulate the climate effects of irrigation.