Dear Referee,

Thank you for your thorough and detailed review, which has been invaluable in enhancing the quality of our manuscript. We appreciate your recognition of the study's relevance, novelty, and extensive nature.

We have carefully considered each of your comments. Below, you will find our responses to the specific points, as well as the revisions we will make to the manuscript to address your suggestions.

Kind regards,
Suqi Guo and Co-authors

Referee 1 Comment 1
This paper is very complicated to comprehend, primarily due to its structure and writing style. The descriptions of experiments and corresponding model simulations are tough to understand. There are a lot of differences among the different model experiments and their simulations. There are multiple variables considered and their interrelations. Consequently, there are multiple figures (seventeen, including the ones in the appendices, and each with multiple subplots!). However, these are not explained in sufficient detail. This makes the results inconclusive. Most of the interpretations are not clear and some of those are speculative in nature.

Response
We appreciate the referee's comments regarding the clarity and structure of our manuscript. In response to the concerns raised, we will revise the text thoroughly to enhance the organization and readability. Below, we address each specific aspect mentioned and provide examples of our revisions.

1. **"The descriptions of experiments and corresponding model simulations are tough to understand."**

We recognize that the original text in Section 2.1 was difficult to comprehend. To improve clarity, we have paraphrased and simplified the language, particularly in Table 1 (now Table 2; see examples of revisions). We have also included a checkerboard pattern in Fig. C1 and linked it to the land cover forcing description in Section 2.1. To enhance the organization of this section, we have now introduced three scenarios together prior to discussing the model divergences in LCLMC implementations, which we have structured as points (i) to (iv). Additionally, as requested by another referee, we created a table summarizing these model divergences in setup. The complete revision will be included in the revised manuscript.

2. **"There are multiple variables considered and their interrelations. Consequently, there are multiple figures (seventeen, including the ones in the appendices, and each with multiple subplots!). However, these are not explained in sufficient detail. This makes the results inconclusive."**

To clarify how our analysis of several variables supports our research aims and to explain our variable choices, we have linked the Results sections to the research aims presented in the introduction (see lines 106-110). We have added a paragraph at the beginning of the Results section to introduce the variables used and the reason.

3. **"Most of the interpretations are not clear and some of those are speculative in nature."**

We have re-evaluated the speculative language used in our interpretations (e.g., “likely,” “could,” “may”). For claims well supported by evidence, we have removed these qualifiers. For instance, “is likely related to a cooling over the boreal latitudes” has been revised to “is related to a cooling over the boreal latitudes,” as temperature change is indeed a driver of carbon stock changes (see line 318). Additionally, we removed the interpretation “In the case of MPI-ESM, this could be driven by warming (Fig. C2a), which increases both plant carbon assimilation and soil decomposition rates,” due to insufficient evidence to support this conclusion (see line 333).

Further, we have rewritten parts of the interpretation sections and display items to enhance clarity:

Examples of revisions in Section 2.1

We have enhanced the readability and structure of the experimental design and the model divergences in the LCLMCs implementation.

Lines 146-164

From this, three LCLMCs scenarios branch off: In the CROP and the FRST scenario, we applied a land cover change to crop or forest plant functional types (PFTs) for the entire hospitable land of a grid cell. This was done for half of all land grid cells (Fig. C1). We chose to change grid cells such that the final land mask has a checkerboard pattern of changed and unchanged land cover (see Fig. C1 for LCLMC distributions in this study; see Winckler et al. (2017a) for illustration on checkerboard approach). By this homogeneous distribution of changed and unchanged grid cells we could apply an established method to separate local and nonlocal effects of LCLMCs (see Sect. 2.2 for more details). The distribution of the specific crop or forest PFTs (e.g., tropical broadleaf evergreen and deciduous forest) remains constant in the changed grid cells (see Appendix A for more details). The IRR scenario uses the CROP scenario and additionally applies each model's native irrigation scheme to all LCLMC grid cells globally (see Appendix B for more details).

Though adopting the identical experimental design, ESMs are diverse in LCLMCs implementations (see Table 2). We summarize the main differences; further details are provided in Appendix B. The exact implementation of LCLMCs depends on the ESM (see Appendix B for more details). (i) DDifferent from the other two models, EC-Earth uses the dynamic vegetation model LPJ-GUESS, which allows PFTs to compete on six stand types (natural, pasture, urban, crop, irrigated crop, and peatland). Consequently, converted cropland or natural land could be further replaced by other PFTs based on climate conditions, leading to less target land cover. (ii). Additionally, Ffor the FRST scenario, we could only prescribe the entire natural stand instead of explicit forest in EC-Earth. As a result, depending on the climate, grassland coexists with the forests and shrubs. Additionally, (iii) I-n EC-Earth, the physical properties of trees gradually establish depending on biomass buildup, in contrast to an immediate physical forest representation in MPI-ESM and CESM. The IRR scenario uses the CROP scenario and additionally applies each model's native irrigation scheme to all LCLMC grid cells globally (see Appendix B for more details).

(iv) DDifferent from the other two models, in EC-Earth the water cycle components between LPJ-GUESS and the atmospheric model (Integrated Forecasting System, IFS) are not coupled. This implies that irrigation affects the water budget only within LPJ-GUESS, without directly impacting the atmosphere through surface water and energy fluxes but not through direct impacts such as changed surface energy fluxes (De Hertog et al., 2023; Döscher et al., 2022).. Thus However, irrigation within LPJ-GUESS influences vegetation growth and physical properties (e.g., leaf area index and vegetation cover), which subsequently impacts the atmosphere biogeochemically by surface energy exchange., irrigation-induced BGP impacts on the atmosphere can only be simulated due to irrigation-induced effects on the physical vegetation properties (e.g., leaf area index, vegetation cover), but not through direct impacts such as changed surface energy fluxes (De Hertog et al., 2023; Döscher et al., 2022).

Revisions to Figure and Tables

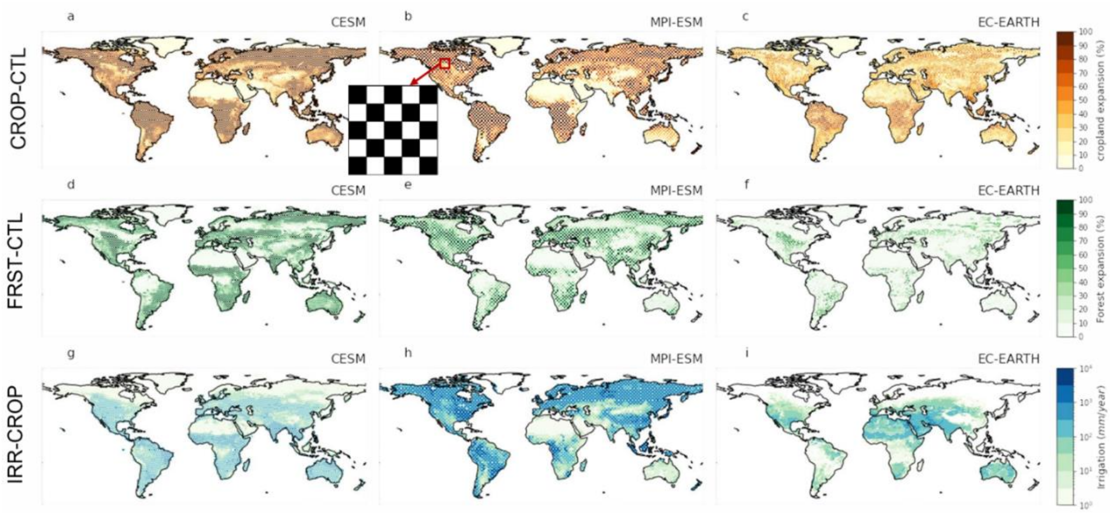


Figure C1: Land-cover and land management changes implemented in the sensitivity ~~experiments~~simulations. The cover fraction increase of cropland in the CROP scenario compared to the CTL scenario is shown for CESM (a), MPI-ESM (b), and EC-Earth (c). The cover fraction increase of forest in the FRST scenario compared to the CTL scenario is shown for CESM (d), MPI-ESM (e), and EC-Earth (f). The amount of irrigation implemented in the IRR scenario compared to the CROP scenario is shown for CESM (g), MPI-ESM (h), and EC-Earth (i). Source: De Hertog et al. (2023).

Table 2~~1~~: Overview of the Earth system model scenarios analyzed in our study, together with a brief description of the simulated land-cover and land management changes (PFT: plant functional type).

Scenario name	**Land cover change**	**Land management change**
Control (CTL)	None. Constant land cover of the year 2014.	No ~~land management other than agriculture (cropland) and grazing (pasture) of the year 2014, i.e.~~ wood harvest ~~levels~~ and irrigation ~~remain at zero.~~
Cropland expansion without irrigation (CROP)	We replace all PFTs that are neither cropland nor bare soil (such as pasture, grassland, shrubland, and forest) in the 2014 land cover with crop PFTs. This ensures cropland occupies 100% of the hospitable land within a grid cell. ~~Starting from CTL, all PFTs that are neither cropland nor bare soil (pasture, grassland, shrubland, forest) were removed, while the fractions of the crop PFTs are increased such that fractions within a grid cell add up to 100 %.~~ Performed on half of the land grid cells in a checkerboard pattern.	No wood harvest and irrigation. ~~land management other than agriculture (cropland) and grazing (pasture) of the year 2014, i.e. wood harvest levels and irrigation remain at zero.~~
Cropland expansion with irrigation (IRR)	Same as in the CROP scenario. Performed on half of the land grid cells in a checkerboard pattern.	Irrigation on all cropland PFTs.
Afforestation (FRST)	We replace all PFTs that are neither forest nor bare soil (such as pasture, grassland, shrubland, and forest) in the 2014 land cover with forest PFTs. This ensures forest occupies 100% of the hospitable land within a grid cell. ~~Starting from CTL, all PFTs that are neither forest nor bare soil were removed, while the fractions of the forest PFTs are proportionally increased such that fractions within a grid cell add up to 100 %.~~ Performed on half of the land grid cells in a checkerboard pattern.	No wood harvest and irrigation.~~land management other than agriculture (cropland) and grazing (pasture) of the year 2014, i.e. wood harvest levels and irrigation remain at zero.~~

Table 3: Comparison of land-cover and land management changes (LCLMCs) implementations across Earth system models (PFT: plant functional type).

LCLMCs implementation	**MPI-ESM**	**CESM**	**EC-Earth**
Land surface scheme	JSBACH3	CLM5	LPJ-GUESS
Dynamic vegetation	No dynamic competition among PFTs	No dynamic competition among PFTs	Dynamic competition among six stand types (natural, pasture, urban, crop, irrigated crop, peatland).
Afforestation implementation	Uses prescribed transitions to forest PFTs.	Uses prescribed land cover states for forest PFTs.	Does not support exact afforestation fractions; afforestation occurs by expanding natural PFT, allowing coexistence of grassland and shrubs.
Plant physical properties establishment	Immediate establishment after land cover change	Immediate establishment after land cover change	Gradual establishment based on biomass accumulation.
Water cycle coupling	Fully coupled between land and atmosphere	Fully coupled between land and atmosphere	Uncoupled to atmospheric model; irrigation has no direct impact on atmosphere (e.g., through surface water and energy fluxes).

Link between variable analysis and research aims

lines 106-110

> More specific aims of our study are (i) to quantify the simulated global development and spatial distribution of nonlocal effects of LCLMCs on different terrestrial carbon pools (Sects. 3.1 and 3.2), (ii) to assess the importance of nonlocal BGC effects in relation to the total effects, which consist of both local and nonlocal BGC effects and represent the overall carbon cycle response at the location of the LCLMCs (Sect. 3.3), (iii) the point in time when the nonlocal BGC effects become larger than the natural internal variability (Sect. 3.4), and (iv) the sensitivity of nonlocal BGC effects to temperature and soil moisture (Sect. 3.5).

Variables' introduction

> First, we analyse the global-integral, transient carbon stocks changes in terrestrial carbon pools (Sect. 3.1). We then concentrate on particular carbon pools that influence total terrestrial carbon stock (cLand) changes as components. Specifically, we analyse changes in vegetation carbon stock (cVeg) and soil (cSoil), due to their dominance. Litter carbon stocks (cLitter) changes, being intermediate and temporal, often present similar but generally minor changes to cSoil (not shown). We also investigate the magnitude and importance of nonlocal BGC effects from both spatial distribution and relative magnitude perspectives (Sects. 3.2 and 3.3). Next, we investigate when these signals are established over time (Sect. 3.4). Lastly, we attribute the nonlocal BGC effects to climate factors, with climate distributions presented in Figs. C2 and C3 (Sect. 3.5).

Referee 1 Comment 2
Perhaps it will be helpful for the readers to categorize the biogeophysical and biogeochemical effects into local and nonlocal categories and represent this information in a table.

Response

We thank the referee for this valuable suggestion and agree that categorizing the biogeophysical and biogeochemical effects into local and nonlocal categories will enhance clarity for readers. In response, we have added a table that summarizes this information and linked it to the corresponding section in the introduction.

Table 1: Definitions of Land-Cover and Land-Management Change (LCLMC) Effects (BGP: Biogeophysical, BGC: Biogeochemical).

LCLMCs effects	Affected regions	Definition
Local BGP effects	Regions with LCLMCs	LCLMCs influence the local climate via energy, water, and momentum fluxes due to changed land surface properties such as albedo, leaf area, and roughness.
Nonlocal BGP effects	Regions without LCLMCs	LCLMCs influence remote climate via advection of the altered air mass properties and possible changes in large-scale circulation.
Local BGC effects	Regions with LCLMCs	LCLMCs directly influence the local carbon emissions and sequestration.
Nonlocal BGC effects	Regions without LCLMCs	LCLMCs influence remote carbon stocks through climate changes driven by nonlocal BGP effects.

Referee 1 Comment 3
How the effects are separated into local and non-local is not objectively defined. Did they use any preset definition of the 'area of influence' or did they use a specific number of neighboring points (pixels) for such classifications?

Response

We appreciate the referee's comment regarding the separation of local and nonlocal effects. We base our signal separation on the approach introduced by Winckler et al. (2017), where the processes are explained in detail (the illustration is provided in the response to Comment 9). We define changed and unchanged grid cells according to the land cover forcing applied in a checkerboard pattern, as clarified in Section 2.1 (Lines 148-151). Additionally, we have included the checkerboard pattern in Fig. C1 to aid in visualizing the setup. To further enhance clarity, we have reiterated this setup in Section 2.2 by adding the following sentence at the beginning:

> We simulate LCLMCs by applying land cover forcing in a checkerboard pattern of changed and unchanged land cover (Fig. C1).

Referee 1 Comment 4
Lines 59-61: I do not totally understand this statement. Changing a forest to grassland will reduce its carbon sequestration, which will increase atmospheric warming. This is a global effect and biogeochemical in nature. On the other hand, an increase in albedo will impart a cooling that is local and biogeophysical in nature.

Response

We appreciate the referee's comment and have revised the relevant section for clarity.

> The nonlocal effects can only be quantified by models. Studies changing forest to grasslands show that idealized deforestation, while it ~~may have~~ can warm~~ed~~ the climate on a global average with local BGP effects, brings about nonlocal BGP effects that cool the climate by several tenths of a degree on global average (Winckler et al., 2019a).

In this context, we focus on the impact of BGP effects on global climate, using this sentence as an introduction to nonlocal BGP effects. We refer to the global impact of local BGP effects to compare them with nonlocal BGP effects and emphasize the importance of nonlocal BGP effects on global mean temperature. While local BGP effects have substantial impacts on local climates, we can also derive a global integral of these effects, which is relevant for global-scale decision-making.

In the comment, there seems to be a misunderstanding regarding local and nonlocal BGC effects, possibly considering the global climate impact (including regions remote from LCLMCs) of biogeochemical effects. LCLMC-induced carbon sequestration and emissions—i.e., the biogeochemical effects of LCLMCs—always influence the global climate through GHG effects. However, we define local and nonlocal BGC effects based on whether the LCLMC-induced carbon pool changes occur locally or in regions remote from the LCLMCs. Local and nonlocal BGC effects are discussed in the following paragraphs. Definitions are also provided in Table 1 (see our response to Comment 2).

Referee 1 Comment 5
Lines 130-135: The second advantage of not considering the plausible realizations in the modeling experiments is not clear.

Response
We appreciate the referee's comment and have clarified the second advantage.

> Second, unlike historical LCLMCs or realistic future scenarios where LCLMCs occur in limited regions, idealized global LCLMCs enable the estimation and comparison of impacts across most regions worldwide.~~Second, by applying large-scale LCLMCs we cover most regions of the world, beyond those that have happened to be affected by historical LCLMCs, and thus improve our understanding of regional differences in LCLMC effects.~~

Referee 1 Comment 6
CROP scenario in Table 1: So, here, basically, two land use types are considered: cropland and bare soil, right? And both these occupy 50% of each of the land grid cells? Are different biophysical and biogeochemical parameters used for the different crop types, such as albedo, rooting depth, etc.?

Response
We appreciate the referee's comments regarding the CROP scenario in Table 1. We recognize that the original text in the table was difficult to comprehend.
To clarify, the bare land fraction is maintained at the 2014 level, reflecting present-day climate conditions. Land cover change occurs only on hospitable land, and the 50% allocation refers to the global LCLMCs represented in a checkerboard pattern.
Regarding the specific plant functional types (PFTs) in the crop and forest categories, we have added the following paragraph at the beginning of Appendix A and linked it to Section 2.1 where PFTs are first mentioned:

Appendix A: Distribution of PFTs within crop and forest categories

> PFTs are used in earth system models to represent the diversity of land cover types within a grid box. These PFTs are grouped by biochemical and biophysical properties, which are represented by model-specific parameters. The number and specific types of PFTs within the crop and forest categories vary among Earth system models. MPI-ESM includes four forest types and one crop type. CESM includes eight forest types and nine crop types, with each crop type having a corresponding irrigated version for irrigation implementation. EC-Earth does not have specific forest types; instead, it uses a natural type that includes forests coexisting with grassland and shrubs, and it includes one crop type along with a corresponding irrigated version.

Referee 1 Comment 7
IRR scenario in Table 1: Since all the croplands were irrigated, did the authors check the hydrological budget and ensure its closure globally? Also, what kind of irrigation was considered, fed with surface or groundwater, drip or canal, etc.? These details are required.

Response
We thank the referee for this comment. MPI-ESM and CESM both use the flood irrigation method, while EC-Earth uses three methods: flood, sprinkler, and drip irrigation. MPI-ESM uses water from surface runoff and drainage, CESM uses water from rivers and oceans, and EC-Earth uses surface, reservoir, and upstream water. We have provided detailed information about the hydrological budget and irrigation methods in Appendix B. We have highlighted the relevant information for MPI-ESM and clarified the details for CESM and EC-Earth. Appendix B has been further linked to Section 2.1 for reader convenience (Line 159).
Appendix B (Lines 596-602)

> Regarding irrigation implementation, for the MPI-ESM, we adapted and implemented a simple irrigation scheme into JSBACH. It assures water mass conservation in a coupled atmosphere/ocean climate model and maximizes the effect of irrigation to recycle locally available water to the atmosphere by evapotranspiration. Surface runoff and drainage are first collected in a storage reservoir with 20 cm capacity before being transferred to the skin reservoir, filling it completely as long as water is available in the storage reservoir. In contrast to MPI-ESM, CESM and EC-Earth do not have a constraint on water availability. CESM applied daily

irrigation to the ~~root zone~~surface to retain a target soil moisture, while EC-Earth applied daily irrigation to the top of the soil column depending on the water deficit. While MPI-ESM and CESM use the flood irrigation method, EC-Earth incorporates three methods: flood, sprinkler, and drip irrigation. In CESM, irrigation water is first taken from river storage, with additional water drawn from the ocean when river water is insufficient. In EC-Earth, irrigation water is first taken from surface and reservoir water, with additional water drawn from neighbour cell surplus when local water is insufficient.

Referee 1 Comment 8
Lines 160-162: See my earlier comment on the water budget.

Response

We appreciate the referee's comment. The details of the water budget are illustrated in Appendix B. For further clarification, please refer to our response to Comment 7.

Referee 1 Comment 9
Section 2.2: The recipe used here to differentiate between the local and non-local effects is not clear. Can the authors show a flowchart summarizing these?

Response

We thank the referee for this suggestion. To clarify the approach used to separate local and non-local effects, we refer to the signal separation approach illustrated in Winckler et al. (2017), which provides a detailed step-by-step explanation. To avoid repetitive work, we prefer to cite this existing literature. Additionally, we include the relevant figure from Winckler et al. (2017) here for further reference:

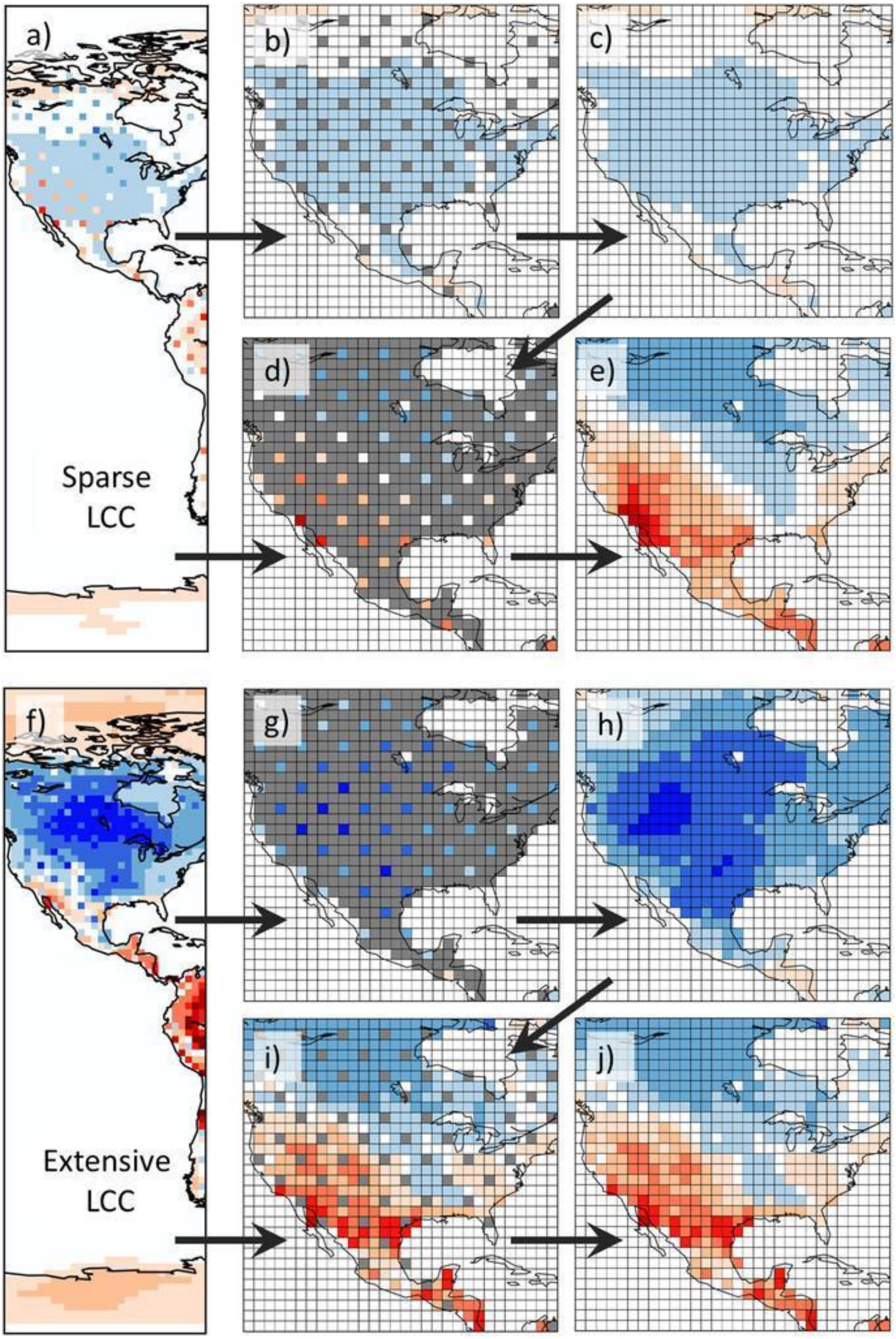


Fig. 1.

Sketch illustrating the separation approach (arbitrary color scale). (a) The simulated signal. The LCC grid boxes stand out because there the signal (local plus nonlocal) is mostly stronger than in the surrounding non-LCC grid cells (only nonlocal). (b) The nonlocal effects at no-LCC boxes. (c) The nonlocal effects are interpolated to LCC boxes. (d) The difference at the LCC boxes between

the simulated signal in (a) and interpolated nonlocal effects in (c) is shown, which we then (e) interpolate in order to obtain global information on the local effects. This approach works analogously for extensive deforestation [(f)–(j)]. Grid boxes whose information is not used for interpolation in (b),(d),(g),(i) are shown in gray. (For results on local and nonlocal effects see Fig. 2.) Source: Winckler et al. (2017a).

Referee 1 Comment 10
Lines 236-241: Why are changes in surface roughness due to land cover change and its impact on aerodynamic conductance not considered?

Response

We appreciate the referee's comment. In Section 2.5 (lines 236-241), we focus on the direct climate drivers (nonlocal BGP effects) that influence nonlocal BGC effects. Changes in land physical properties, including albedo, roughness, and evapotranspiration, are indeed sources of both local and nonlocal BGP effects, as well as nonlocal BGC effects. While we consider nonlocal BGP effects—such as changes in temperature and moisture—we indirectly account for surface roughness. To isolate the specific contribution of roughness, simulations that explicitly impose changes in roughness are necessary to determine its impact on local and remote climate (Winckler et al., 2019), and subsequently, on the remote carbon cycle.

The definitions of local and nonlocal biogeophysical and biogeochemical effects are provided in the introduction section. To clarify, we reiterate them here for better understanding:

(i)Local biogeophysical effects arise from local LCLMCs, influencing the local climate through energy, water, and momentum fluxes due to altered land surface properties such as albedo, leaf area, and roughness.
(ii)Nonlocal biogeophysical effects occur when the advection of altered local air mass properties, combined with changes in large-scale circulation, affects remote climate.
(iii)Nonlocal biogeochemical effects result from changes in remote climate that further influence remote carbon stocks.
In Section 2.5, we analyze step (iii), acknowledging the potential and novelty of attributing nonlocal biogeochemical effects to specific surface physical properties.

Referee 1 Comment 11
Figure 2: Please improve the description of different components of the terrestrial carbon cycle simulated by different models. In the present format, it is utterly confusing for the readers. For example, what about the blue dashed line? To interpret this the reader has to read the caption. Why then some other lines are described in the figure itself? Use a uniform and detailed description and present those in a way straightforward to understand.

Response

We appreciate the referee's feedback and have revised the legend of Figure 2 to improve clarity. Specifically, we have provided separate legends by presenting the carbon pools in different colors and the models in different line patterns. Additionally, we have changed the line pattern color in the legend for models to a neutral light grey to avoid confusion. The usage of colors and patterns is uniform through all the subplots in the figure, for instance, the blue dashed lines show time series of the litter carbon pool from CESM simulations in all the subplots. We also revised the caption of Figure 2 for further clarification.

Figure 2

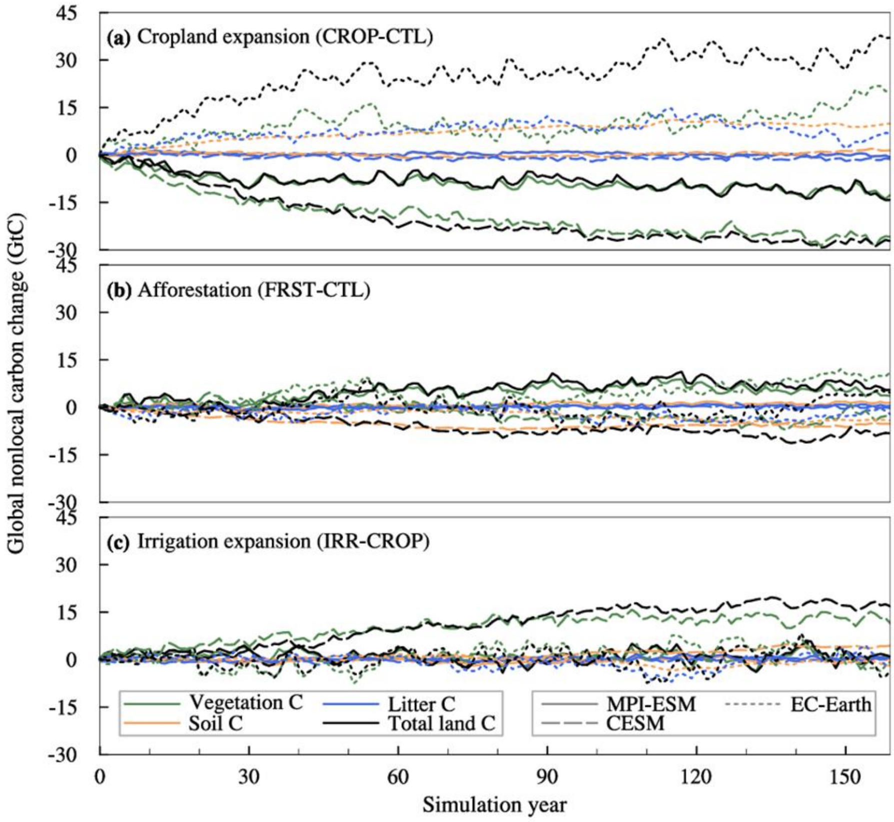


Figure 2: Simulated nonlocal effect on the development of global terrestrial carbon pools after an idealized change of 50 % of all grid cells: (a) ~~to~~ cropland expansion (b) afforestation (c) irrigation of cropland expansion. ~~**Carbon pools are separated into vegetation (green), soil (orange), litter (blue), and land as the total terrestrial C pools (black) between results of MPI-ESM (solid lines), CESM (dashed lines), and EC-Earth (dotted lines).**~~**The total land carbon (black) is separated into vegetation (green), soil (orange), and litter (blue) pools. The results for MPI-ESM (solid lines), CESM (dashed lines), and EC-Earth (dotted lines) are shown for each carbon pool and for total land carbon.**

Referee 1 Comment 12
Figure 3: How are the boxes selected in panel (a) for calculating the regional averages? The boxes over northern America and Australia include oceans as well, which should not be counted in the terrestrial carbon cycle. Why don't the authors use appropriate shapefiles to select and crop the regions of their interest?

Response

The regions were selected based on three reasons: they show a strong nonlocal signal, consistency across models, and represent a range of latitudes. We clarified the reasons with the following revision:

> We aggregate results to a few core regions. These regions were chosen because they exhibit a large absolute nonlocal signal and the signal across models is consistent (Fig. 5, 6). Additionally, we choose regions across various latitudes to capture latitudinal diversity.

The inclusion of ocean areas in the selected regions does not affect our results, as we calculate the total terrestrial carbon, which is zero over oceans. While this approach might lead to differences if we were analyzing carbon density changes normalized by area, it remains accurate for our purposes. To address any potential confusion, we have revised the caption for Fig. 5 as follows:

Figure 5: Relative contribution of the nonlocal to total effect of LCLMC on vegetation carbon of the last 30 years in the 160 year simulation period using MPI-ESM (~~blue~~green), CESM (blue~~red~~), and EC-Earth (orange) for (a) cropland expansion, (b) afforestation, and (c) irrigation of cropland expansion. Values are separated into the global integral (global) and regional means for Eastern North America ~~North America~~ (ENA), ~~Amazon~~ Western Amazon (WA~~AM~~), Central Congo Basin~~Congo~~ (~~CG~~CCB), Northern Eurasia~~North Eurasia~~ (NE), Northeastern Asia ~~East Asia~~ (NEA), Southern Southeast Asia ~~Southeast Asia~~ (SSEA), and Northern Australia~~Australia~~ (NAU). Regions are defined within the red boxes in Fig. 3a, and only terrestrial areas are considered. ~~See red boxes in Fig. 3a for the location of the regions.~~

Referee 1 Comment 13
Can the authors show spatial trends of different carbon pools for different experiments and models over the simulation period for the aforementioned regions?

Response

We thank the referee for this valuable suggestion. We interpret it as having two possible meanings: (1) displaying time series of spatially averaged values, or (2) presenting global maps that illustrate the trends of carbon pools (calculated as the slope of linear regressions). We find both interpretations to be valuable.

However, given that the carbon pools do not change linearly over the simulation period and instead show saturating trends in some cases across models and scenarios, we have opted to focus on time series for the selected regions. We have created figures showing the development of different carbon pools in the selected regions, which are added in Appendix D. These figures helped us gain a better understanding of the global integrated nonlocal BGC signal in Sect. 3.1 and the time of emergence in Sect. 3.4, and we have integrated the relevant discussion into the main text.

Example figure

Appendix D: Temporal development of regionally integrated nonlocal BGC effects

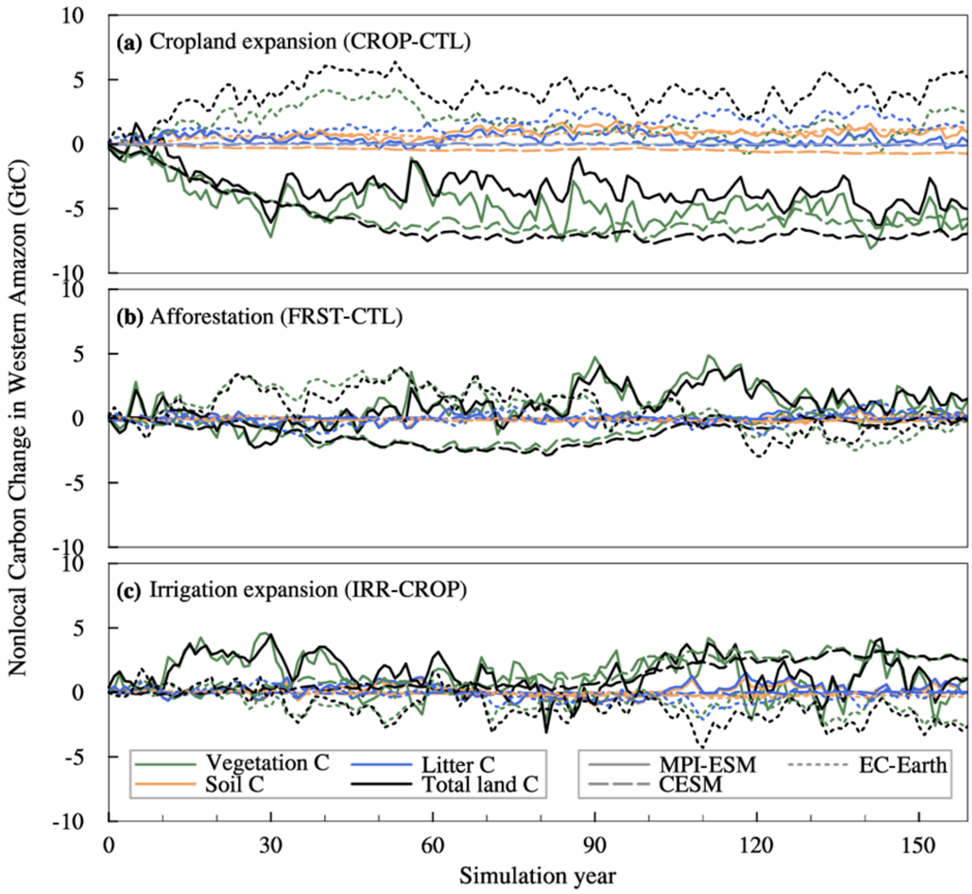


Figure D1: Simulated nonlocal effect on the development of terrestrial carbon pools in the Western Amazon after an idealized change of 50 % of all grid cells: (a) cropland expansion (b) afforestation (c) irrigation of cropland expansion. The total land carbon (black) is separated into vegetation (green), soil (orange), and litter (blue) pools. The results for MPI-ESM (solid lines), CESM (dashed lines), and EC-Earth (dotted lines) are shown for each carbon pool and for total land carbon.

Relevant discussion:

Lines 281-283

> Additionally, the nonlocal BGC stock changes show strong interannual variability, particularly in MPI-ESM and EC-Earth, which can be related to internal climate variability (Loughran et al., 2021). This variability is primarily driven by the Western Amazon region, while the Central Congo Basin shows much weaker variability (see Appendix D for details). This variability is related to the internal climate variability, which varies across regions (Loughran et al., 2021).

Lines 380-385

> The mid-latitudes show a later ToE, with different magnitudes across models. For example, Eastern North AmericaNorth America typically shows a later ToE for all three models while North Eurasia also shows a late ToE for CESM and EC-Earthwhich is indicated by the relatively flat trend in the temporal development of carbon pools during the initial decades (Figs. E1 and D4). These regions are primarily characterized by Ccrop- and grasslands take a considerable fraction of land in Eastern North America, indicating that the response of those land cover types is slower than that of forests. However, for MPI-ESM and CESM, the nonlocal BGC effect in Eastern North AmericaNorth America reaches a magnitude similar comparable to that in Northern EurasiaNorth Eurasia, East Asia Northeastern Asia, and Southern Southeast Asia Southeast Asia by the end of the simulation period (see Fig. 3 and Appendix D for details). This suggests that the nonlocal climate impact on crop- and grasslands persistently accumulates over

time, and ultimately becomes comparable to that on forests.

Referee 1 Comment 14

Consistent scales should be used across the subplots in all the figures. For example, the scales on the y-axis are different in the subplots of Figure 2. Similarly, the x-axis scales are different in panels (d), (h) and (l) in Figure 3. This makes the intercomparison difficult.

Response

We thank the referee for this valuable suggestion. Regarding Figure 2, we realize that the current presentation may cause some confusion. The y-axis scales are actually consistent across the subplots in Figure 2. However, to reduce confusion, we have now added the same top and bottom values for the y-axis in panels (b) and (c), which were initially removed to maintain a clean and compact look since these panels do not span the full range of values as displayed in panel (a) (see Figure 2 in our response to Comment 11)

For Figures 3 and 4, we have made the x-axis scales consistent in panels (d), (h), and (l) to improve comparability. However, in Figures 5 and 6, it is challenging to use a consistent y-axis scale across all panels due to the substantial difference in magnitude among different scenarios. Consistent scales would render some signals nearly invisible. A similar issue applies to Figures 9 and 10, where large differences in magnitude—ranging from several times to an entire order of magnitude—make consistent scaling impractical for both the spatial maps and latitudinal mean plots. For Figures 7 and 8, we have already employed consistent scales across all subplots.

Figure 3:

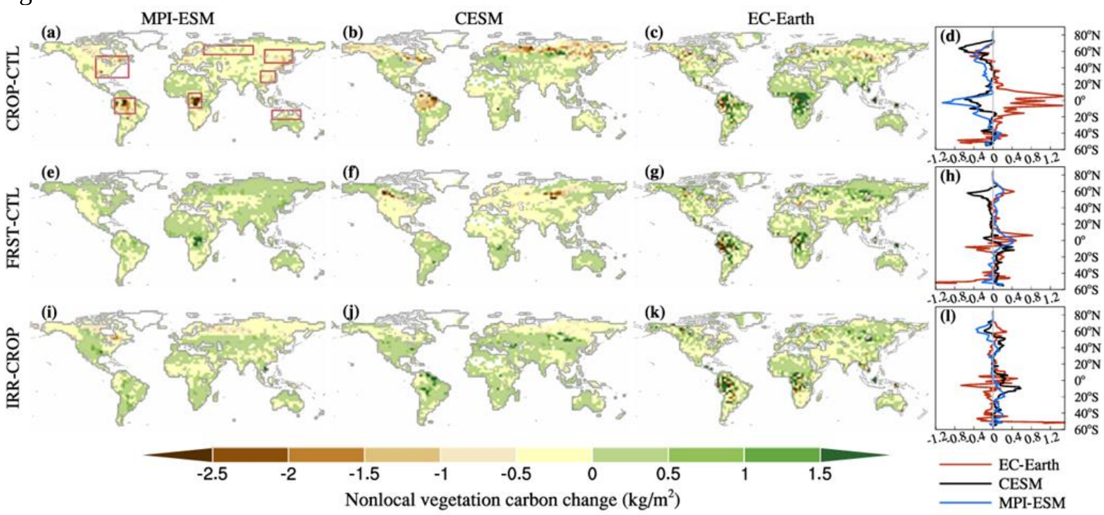
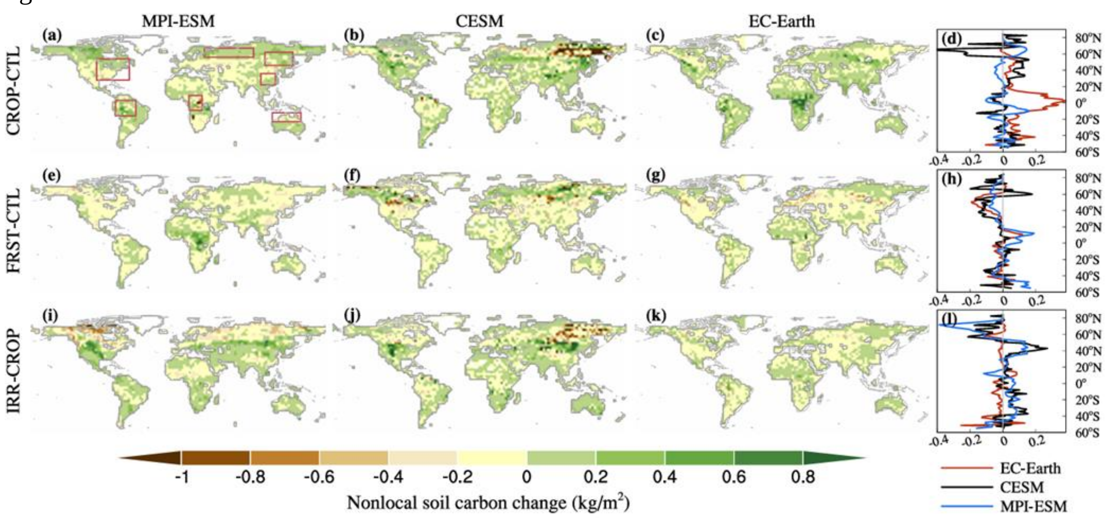


Figure 4:



Referee 1 Comment 15
Lines 379-383: Shouldn't the ToE for the forested regions should be slower than croplands and grasslands, since the total biomass content is significantly higher in the former land use type?

Response

We thank the referee for this comment. Our simulations indicate that the ToE for forested regions occurs earlier than in cropland and grassland regions. We explained this in the Discussion section (lines 494-497), where we link to the Methods section for the relevant definitions of noise and signal for clarity.

Based on these definitions, we explain this signal in detail as follows: we define noise as the variability of carbon pools in the CTL scenario, which reflects internal natural variability. Forested regions exhibit higher noise due to their high biomass density, making them more sensitive to internal climate variability. High biomass density also amplifies the signals, representing the response of the carbon cycle to nonlocal climate changes. The amplification is stronger for signals that consider larger nonlocal climate changes relative to natural variability. Additionally, forested regions experience more substantial climate signals in the CROP scenario, further accelerating the ToE compared to other land-use types.

Line 494-497:

> In addition, dense forests experience an earlier ToE than other types. One reason is the higher sensitivity of carbon pools in these regions to nonlocal BGP effects (Fig. 9 and 10), which is caused by the high biomass density of the forest. For the CROP scenario, the transition from forest to cropland in the Amazon and Congo region (Fig. C1) causes substantial nonlocal BGP effects on nearby regions.

Referee 1 Comment 16
Figure C1: What do the panels j and k stand for? This should be described in the figure caption.

Response

We appreciate the referee's observation. The subplots j and k, which were initially included for the wood harvest scenario, have been removed as they are not discussed in the manuscript.

Referee 1 Comment 17
Several references cited in the text are missing from the bibliography, such as Arora et al.

Response

We thank the referee for this observation. We confirm that Arora et al. is indeed cited in the reference list (lines 677–679). Upon reviewing the manuscript, we also identified a missing reference, which has now been added as follows:

> Loughran, T. F., Boysen, L., Bastos, A., Hartung, K., Havermann, F., Li, H., Nabel, J. E. M. S., Obermeier, W. A., and Pongratz, J.: Past and future climate variability uncertainties in the global carbon budget using the MPI Grand Ensemble, Global Biogeochem. Cy., 35, e2021GB007019, https://doi.org/10.1029/2021GB007019, 2021.

Referee 1 Comment 18
Technical corrections: **1. Line 165: "are shown" instead of "is shown".** **2. Figure 5: CESM is marked blue; however, in the caption, it is written as red.** **3. Lines 467-483: This is a big paragraph. Consider breaking it into two or more.**

Response

1. We have revised Line 165 as follows:

   > The global distributions of land-cover changes and magnitude of irrigation application ~~is~~ are shown in Fig. C1.

2. We have revised the caption of Figure 5 as follows:

Figure 5: Relative contribution of the nonlocal to total effect of LCLMC on vegetation carbon of the last 30 years in the 160 year simulation period using MPI-ESM (~~blue~~green), CESM (blue~~red~~), and EC-Earth (orange) for (a) cropland expansion, (b) afforestation, and (c) irrigation of cropland expansion. Values are separated into the global integral (global) and regional means for Eastern North America ~~North America~~ (ENA), ~~Amazon~~ Western Amazon (WA~~AM~~), Central Congo Basin~~Congo~~ (~~CG~~CCB), Northern Eurasia~~North Eurasia~~ (NE), Northeastern Asia ~~East Asia~~ (NEA), Southern Southeast Asia ~~Southeast Asia~~ (SSEA), and Northern Australia~~Australia~~ (NAU). Regions are defined within the red boxes in Fig. 3a, and only terrestrial areas are considered. ~~See red boxes in Fig. 3a for the location of the regions.~~

3. We have broken the paragraph into two shorter paragraphs for readability.

References

Winckler, J., Reick, C. H., and Pongratz, J.: Robust Identification of Local Biogeophysical Effects of Land-Cover Change in a Global Climate Model, J. Clim., 30, 1159–1176, https://doi.org/10.1175/JCLI-D-16-0067.1, 2017.

Winckler J., Reick C. H., Bright R. M., and Pongratz J.: Importance of surface roughness for the local biogeophysical effects of deforestation, J. Geophys. Res., 124, 8605–8616, https://doi.org/10.1029/2018JD030127, 2019.