Dear Referee,

First of all, thank you for taking your valuable time to review our manuscript which we want to publish in the journal Earth System Dynamics. We are thankful for your generally very positive feedback, that you judge our study as a timely effort and that you share the opinion that local-nonlocal BGC effects of LCLMCs are so far neglected in scientific literature. We also hope to stimulate further investigations in this field.

We carefully went through your comments (published here https://doi.org/10.5194/egusphere-2024-2387-RC2) and hope that we could address all the suggestions, issues and concerns that you raised in your referee comment.

Below you find our responses to the specific points you raised, if needed, additionally with the corresponding text paragraph and how we changed it in order to address your suggestions or concerns.

Thank you again for your valuable input,
Kindest regards,
Suqi Guo and co-authors

Referee 2 Comment 1
Although this is a first attempt to study the nonlocal BGC effects using model sensitivity simulations, a model ensemble involving multiple ESMs, would have been more appropriate for the study. Model ensemble mean and spread would add more insights into the effects of LCLMCs. Authors can consider this aspect.

Response

We appreciate the referee's suggestion regarding the use of a model ensemble mean and spread for added insight. While this approach is valuable for a large number of models, the current study involves only three models with a relatively large spread in their responses. Given the small ensemble size, calculating a robust and representative ensemble mean is challenging and may not yield reliable results. Therefore, we would rather investigate individual model results and in this way the common features and differences among the three models can be identified for further attribution and process understanding.

Referee 2 Comment 2
There are noticeable differences in the simulated nonlocal BGC effects among three ESMs, reflected in spatial maps, latitudinal means, and sub-regions. This is expected; however, separate sub-sections within "Results" sections should be devoted to explaining the differences (on each aspect considered)

Response

Thank you for your suggestion. We will restructure and include a dedicated paragraph in each results section to explain the differences among models. For example, in Sect. 3.1, we addressed the divergence in model responses regarding the magnitude, trend, and variability of the global-integral nonlocal BGC effects.

> There are several reasons for the divergence across models regarding the magnitude, trend and variability of global-integral, transient nonlocal BGC effects. First, the magnitude divergence is dominant by some key regions where nonlocal BGP effects diverge considerably (see Sect. 3.2). For example, for the CROP scenario, ~~These~~ opposing nonlocal ~~BGC stock~~cVeg and cLand ~~effects~~changes between MPI-ESM/CESM and EC-Earth are mainly caused by opposing c~~Land signals~~Veg changes in the Western Amazon~~Amazon and the Congo~~ region due to opposing nonlocal climate conditions (see Sect. 3.2.1,~~ and~~ Sect. –3.5 and Appendix D for details). Additionally, divergence in trend and variability is related to how each model's land surface scheme handles LCLMCs (see Sect. 2.1). For example, for the FRST scenario, ~~In EC-Earth,~~ the dynamic vegetation competition and replacement, as well as the gradual establishment of tree physical properties induce ~~the~~ oscillations -in EC-Earth between ~~a~~ gains and losses in nonlocal ~~BGC stock gain and loss~~carbon pools during the simulation period.~~ can be attributed to the dynamic vegetation competition and replacement, as well as the gradual establishment of tree physical properties.~~

Referee 2 Comment 3
The whole analysis of the sensitivity simulations can be improved by avoiding multiple spatial maps and focusing on latitudinal means (e.g., Figure 3 d, h, l) and sub-regional contributions (e.g., Figure 5, 6).

Response

We appreciate the referee's suggestion. We have moved the spatial maps from Figures 7 and 8 to the Appendix and revised Section 3.4 to focus on the latitudinal means. However, we chose to retain the other maps, as they enhance our analysis and provide a more comprehensive perspective.

Specifically, the spatial maps in Figures 3, 4, 9, and 10 offer an intuitive overview of the signal-dominant regions or those most sensitive to climate factors within each latitude band. These regions correlate with the initial PFT distributions, such as forests, grasslands, or croplands. This spatial context can be lost or less apparent when presenting only latitudinal means and sub-regional contributions.

Additionally, the spatial maps in Figures 3 and 4 clarify interactions among regions by illustrating how signals either enhance or offset across areas. This comprehensive spatial perspective helps to reveal regional relationships and interactions that may otherwise remain obscured. We believe that the present arrangement of figures keeps a good balance of showing integrated information with the latitudinal and regional means and more details of regional features and distributions with spatial maps.

Figures 7 and 8

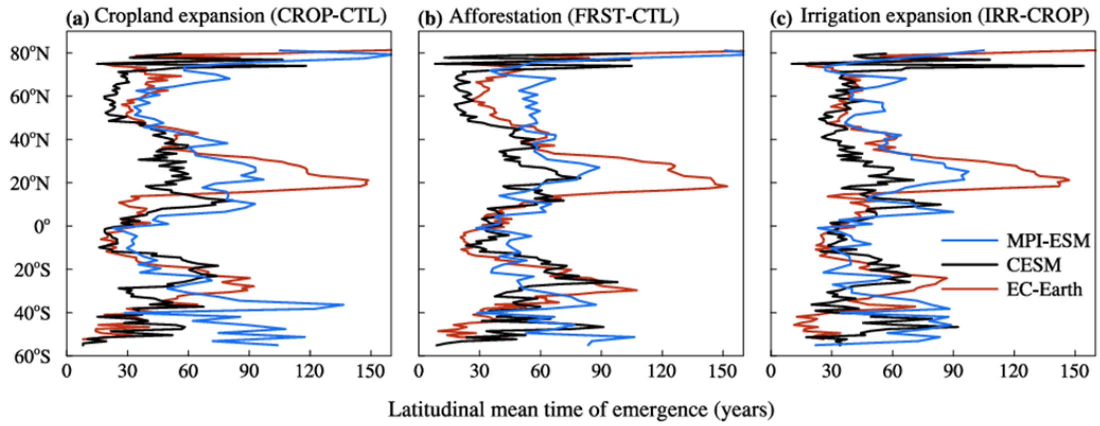


Figure 7: Latitudinal mean time of emergence for nonlocal vegetation carbon changes surpassing natural variability in the (a) cropland expansion, (b)afforestation, and (c) irrigation of cropland expansion scenario (c). Results are shown for MPI-ESM (blue), CESM (black), and EC-Earth (red).

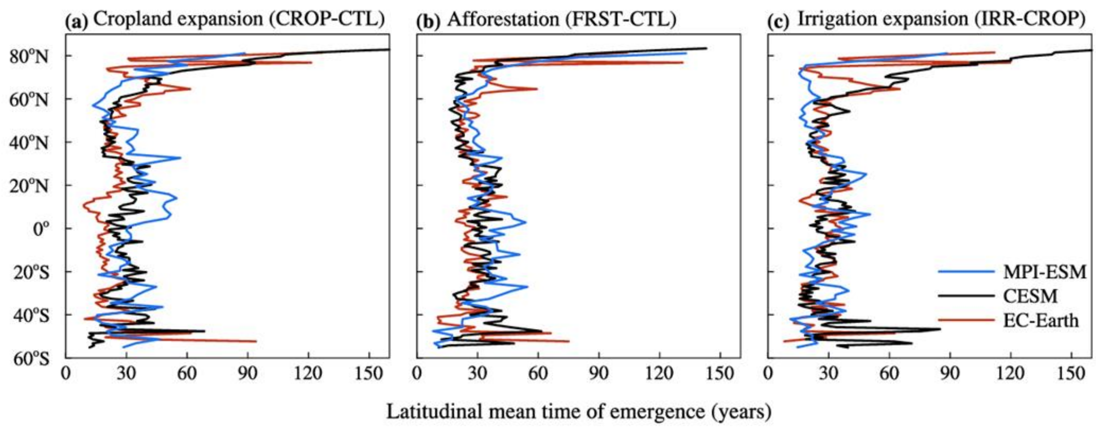


Figure 8: Latitudinal mean time of emergence for nonlocal soil carbon changes surpassing natural variability. For details see Fig. 7 | Same as Fig. 7 but for soil carbon.

Lines 378-401

3.4 Time of emergence

Generally, nonlocal cVeg changes emerge within less than 40 years (Figs. 7 and E1) for the majority of the hospitable land area for all LCLMC scenarios. The latitudinal mean ToE shows a similar pattern of variation with latitude across models and scenarios. In the tropics and Northern Hemisphere high latitudes, the ToE occurs earlier, typically within 30 years. In the tropics, this early ToE is dominated by ~~For the CROP scenario, the ToE for~~ the Western Amazon~~Amazon~~ and ~~Congo~~ Central Congo Basin, i.e. for rather forested regions, with ~~decreasing nonlocal cVeg signal is~~ToE could be even shorter than ten years, ~~for MPI-ESM and CESM~~depending on the model and scenario (Fig. E1). The mid-latitudes show a later ToE, with different magnitudes across models. For example, Eastern North America~~North America~~ typically show~~s~~ a later ToE ~~for all three models while North Eurasia also shows a late ToE for CESM and EC-Earth~~which 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~~ C~~c~~rop- 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 America~~North America~~ reaches a magnitude ~~similar~~ comparable to that in Northern Eurasia~~North 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.

~~Similarly, for FRST and IRR scenarios, the ToE is shortest in regions with largest nonlocal cVeg changes by the end of the simulation period. This comprises small regions within the Congo and the Amazon, and the North Eurasia region for CESM and EC-Earth~~. ~~EC-Earth generally shows a large magnitude of nonlocal cVeg changes in the Amazon and Congo regions for all scenarios. However, the ToE is generally larger than in MPI-ESM and CESM. The reason could again be the effect of the dynamic vegetation competition and replacement. Additionally, for the FRST scenario, gradual establishment of tree physical properties delays the growth trend and ToE.~~

For cSoil, the ToE is also generally shorter than 40 years ~~in~~ for the majority of the hospitable land area for all scenarios and models (Figs. 8 and E2~~8~~). The latitudinal mean ToE shows smaller variation for all models and scenarios. The ToE for cSoil is typically shorter than that for cVeg, which is related to the relatively smaller internal variability of cSoil. ~~In most cases, the ToE is shorter in regions with large nonlocal cSoil changes, for example: the Amazon and Congo regions in MPI-ESM and EC-Earth for the CROP scenario; the Congo region in MPI-ESM for the FRST scenario; the North America region in MPI-ESM and CESM for the IRR scenario. In contrast, for EC-Earth, even though nonlocal cSoil changes are smaller than nonlocal cVeg changes in key regions like the Amazon, Congo, and North Eurasia, the ToE is typically shorter. This could be due to the relatively smaller internal variability of cSoil.~~

Referee 2 Comment 4
The abstract and conclusion sections should contain some quantitative statements: the magnitude of nonlocal BGC compared to total effects (%) on different regions, impacts of temperature on BGC effects, etc.

Response

We appreciate the referee's suggestion. We already show quantitative data for time of emergence, total BGC effects globally and region specific. We now additionally include the nonlocal to total BGC effects ratio in both the abstract and conclusion sections. Additionally, in the conclusion section, we add quantitative data for the sensitivity of carbon cycle components to changes in climate variables. To avoid overloading the abstract with details, we focus on the overall importance of nonlocal BGC effects in the abstract, while including specific sensitivities in the conclusion for those interested in further attribution analysis.

Revised sentence in the abstract (Lines 34-35):

For the irrigation scenario, the nonlocal BGC effects are comparable to the total BGC effects with the nonlocal-to-total ratio for vegetation carbon pools commonly reaching around 90%.

Revised sentences in the conclusion (Line 566):

For the IRR scenario, the nonlocal BGC effects are typically comparable or exceed the total effects with the nonlocal to total ratio for vegetation carbon pools commonly reaching around 90%.. Nonlocal BGC effects can be attributed to nonlocal climate changes such as changes in temperature and soil moisture, with tropical regions being particularly sensitive. In these regions, every Kelvin increase in temperature results in a decrease of over 10 GtC in cVeg. The cVeg response to soil moisture changes varies across models, with each millimeter increase in soil moisture leading to a rise in cVeg of +85 to more than +200 GtC.

Referee 2 Comment 5
The definition and discussion of local versus non-local and BGP versus BGC were described in detail in the introduction section. The first 4-5 sentences of the abstract can be rewritten to comprehend these aspects concisely. An additional table (in addition to Figure 1; a nice figure!) can be included and discussed in the introduction section itself to make these definitions clearer to the readers.

Response

We thank the referee for these valuable suggestions. We have rewritten the considered sentences of the abstract the following:

Land-cover and land management changes (LCLMCs) have a substantial impact on the global carbon budget and, consequently, global climate via. the biogeochemical (BGC) effects. The commonly considered BGC effects refer to the direct influence of LCLMCs on local carbon stocks, namely the local BGC effects. However, LCLMCs also influence climate by altering the local surface energy balance due to changes in land surface properties such as albedo, leaf area, and roughness, namely local biogeophysical (BGP) effects. Altered local air mass properties can impact regions remote from LCLMCs through advection and changes in large-scale circulation, namely nonlocal BGP effects. ~~BGP effects act locally, but also nonlocally through advection or atmospheric circulation changes.~~ Previous studies have shown potentially substantial nonlocal BGP effects on temperature and precipitation. Given that the terrestrial carbon cycle strongly depends on climate conditions, this raises the question of whether LCLMCs can trigger remote carbon cycle changes, namely the nonlocal BGC effects - a currently overlooked potentially large climate and ecosystem impact. To assess ~~these nonlocal biogeochemical (BGC) effects~~the nonlocal BGC effects, we analyze sensitivity simulations for three selected types of hypothetical large-scale LCLMCs: global cropland expansion, global cropland expansion with irrigation, and global afforestation, which were performed by three state-of-the-art Earth system models.

Additionally, we have added the following table to clarify the definitions of local versus nonlocal and BGP versus BGC effects.

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 directly 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 the climate of remote regions 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 by changing the local vegetation type or its management.
Nonlocal BGC effects	Regions without LCLMCs	LCLMCs influence the carbon stocks of remote regions through climate changes driven by nonlocal BGP effects.

Referee 2 Comment 6
The specifics of the three models (and their differences, e.g., use of LPJ in EC-Earth) are explained in detail in the methods section (Sect. 2.1). It would be better if the authors added a table listing three model details that are important for the analysis in this study.

Response

We thank the referee for this helpful suggestion. We have added the following table to Section 2.1 to provide a concise overview of the key differences among the three models regarding LCLMCs implementation.

Table 2: 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	Dynamic competition among PFTs switched off	Dynamic competition among PFTs switched off	Dynamic competition among six stand types (natural, pasture, urban, crop, irrigated crop, peatland).
Afforestation implementation	Uses prescribed transitions to model intrinsic forest PFTs.	Uses prescribed land cover states for model intrinsic 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).

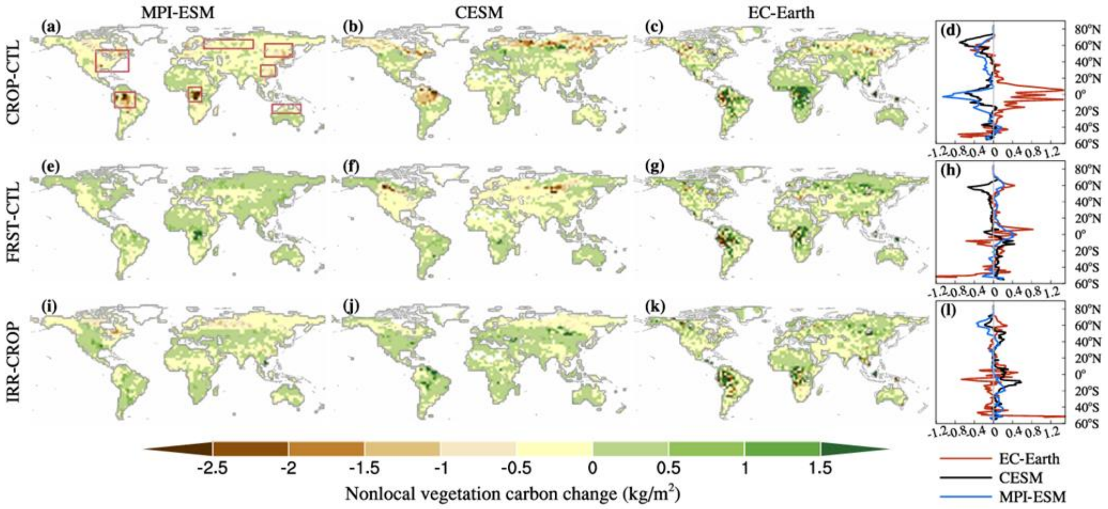
Referee 2 Comment 7

Better assigning different colors to different models in Figure 3 d, h, l (latitudinal means) to distinguish between color scales in the spatial maps.

Response

We appreciate the referee's suggestion, which highlights the potential confusion caused by the similar color schemes. In the latitudinal mean plots, we have now employed distinct colors different from those used in the spatial maps to enhance clarity.

Figure 3:



Referee 2 Comment 8

The naming of different regions (Figures 3a and 5) should be more careful: North America to Eastern NA, Northern Australia, etc

Response

We appreciate the referee's attention to the accuracy of regional names. We have revised the names to be more geographically descriptive as follows: Eastern North America (ENA), Western Amazon (WA), Central Congo Basin (CCB), Northern Eurasia (NE), Northeastern Asia (NEA), Southern Southeast Asia (SSEA), and Northern Australia (NAU). These updated names have been consistently applied throughout the manuscript.

Referee 2 Comment 9
It is better if the authors are consistent while describing the three scenarios in the following order: CROP, IRR, and FRST, throughout the manuscript.

Response

We agree that maintaining consistency in describing the three scenarios enhances the organization of the manuscript. We have reorganized the order of the scenarios to follow the suggested sequence: CROP, IRR, and FRST throughout the text.