Project: **1147**

Project title: **LAnd MAnagement for CLImate Mitigation and Adaptation**

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During the report period we published one paper in the Copernicus Journal *Earth System Dynamics* and submitted one other paper, which is currently under review in the journal *Science Advances*. These papers and the analyses within, were only possible by making use of the DKRZ computation and storage infrastructure. We will briefly report about the content of one published and the one submitted papers here.

1. Remote carbon cycle changes are overlooked impacts of land cover and land management changes (doi: 10.5194/esd-16-631-2025)

In this study, we analyze how land cover and land management changes (LCLMCs, cropland expansion with and without irrigation and afforestation) can influence the global carbon cycle not only locally but also in distant regions through indirect climatic effects. Former research has focused on local biogeochemical (BGC) impacts, i.e., changes in carbon storage at the site of land modification. However, LCLMCs also alter surface energy balances and atmospheric circulation patterns (biogeophysical or BGP effects), which can propagate climate changes to remote regions. These remote climatic shifts, in turn, may modify carbon storage elsewhere, producing nonlocal BGC effects which are largely overlooked until now.

Using three Earth system models (MPI-ESM1.2, CESM2, and EC-Earth3-Veg) and a specific experimental setup to separate between local and nonlocal effects, we quantified nonlocal BGC effects for three idealized global scenarios of cropland expansion (with and without irrigation) and afforestation. Simulations spanning 160 years revealed that remote carbon changes accumulate over time, becoming detectable within about 40 years and reaching magnitudes of 1–37 Gt C globally. The strongest remote signals occurred in the Amazon and Congo Basin forests. In the irrigation scenario, nonlocal effects on vegetation carbon were particularly large—up to 90 % of total carbon changes—highlighting their comparable importance to local effects.

Overall, the study demonstrates that land-use decisions can trigger substantial carbon cycle feedbacks far from where the changes occur. Accounting for these remote carbon impacts is therefore crucial for accurately evaluating land-based climate mitigation and adaption strategies.

2. Framework for mapping land-use effects on carbon and climate across perspectives (under review in Science Advances)

This study presents a novel framework to systematically map how Land Use, Land-Use Change, and Forestry (LULUCF) activities affect both climate and carbon across spatial and decision-making scales. Traditional policy assessments mainly consider local biogeochemical (BGC) effects, that is changes in carbon storage and emissions at the site of land use change, while often neglecting biogeophysical (BGP) effects (alterations in surface energy and water fluxes) and nonlocal effects (climate and carbon responses in distant regions). To bridge this gap, we propose a multi-perspective framework that classifies LULUCF impacts into four actor-based perspectives: (1) global climate and carbon and the three regional perspectives, (2) regional climate, (3) regional climate and carbon, and (4) reciprocal climate and carbon impacts.

Using simulations from three Earth system models (CESM2, MPI-ESM1.2, EC-Earth3-Veg) under three idealized scenarios, global cropland expansion with and without irrigation, and afforestation, our study quantifies the relative importance of local and remote BGP and BGC effects. Results show that global mean temperature (GMT) changes are dominated by local BGC effects, while regional climates are more influenced by local and nonlocal BGP effects. For instance, tropical cropland expansion causes strong local warming (+0.9 °C) through reduced evaporative cooling, whereas afforestation leads to regional cooling and carbon sequestration. Nonlocal BGP and BGC effects, though smaller globally, can significantly alter carbon stocks and agricultural productivity in remote regions.

Our proposed framework provides a scientific and communication tool that aligns diverse policy and management perspectives, from global treaties (e.g., UNFCCC) to local land users, by clarifying which effects matter at each scale. By integrating local and remote biogeophysical, biogeochemical interactions, our study supports more holistic, cross-scale land-use policies that balance climate mitigation, adaptation, and sustainable development goals (SDGs).