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Integrating land management into Earth system models: the importance of land use transitions at sub-grid-scale

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Recent studies indicate that changes in surface climate and carbon fluxes caused by land management (i.e. modifications of vegetation structure without changing the type of land cover) can be as large as those caused by land cover change. Further, such effects may occur on substantial areas: while about one quarter of the land surface has undergone land cover change, another fifty percent are managed. This calls for integration of management processes in Earth system models (ESMs). This integration increases the importance of awareness and agreement on how to diagnose effects of land use in ESMs to avoid additional model spread and thus unnecessary uncertainties in carbon budget estimates.

Process understanding of management effects, their model implementation, as well as data availability on management type and extent pose challenges. In this respect, a significant step forward has been done in the framework of the current IPCC's CMIP5 simulations (Coupled Model Intercomparison Project Phase 5): The climate simulations were driven with the same harmonized land use dataset that, different from most datasets commonly used before, included information on two important types of management: wood harvest and shifting cultivation. However, these new aspects were employed by only part of the CMIP5 models, while most models continued to use the associated land cover maps.

Here, we explore the consequences for the carbon cycle of including subgrid-scale land transformations ("gross transitions"), such as shifting cultivation, as example of the current state of implementation of land management in ESMs. Accounting for gross transitions is expected to increase land use emissions because it represents simultaneous clearing and regrowth of natural vegetation in different parts of the grid cell, reducing standing carbon stocks. This process cannot be captured by prescribing land cover maps ("net transitions"). Using the MPI-ESM we find that ignoring gross transitions underestimates emissions substantially, for historical times by about 40%.

Implementation of land management such as gross transitions is a step forward in terms of comprehensiveness of simulated processes. However, it has increased model spread in carbon fluxes, because land management processes have been considered by only a subset of recent ESMs contributing to major projects such as IPCC or the Global Carbon Project. This model spread still causes the net land use flux to be the most uncertain component in the global carbon budget. Other causes have previously been identified as differences in land use datasets, differing types of vegetation model, accounting of nutrient limitation, the inclusion of land use feedbacks (increase in atmospheric CO_2 due to land use emissions causing terrestrial carbon uptake), and a confusion of whether the net land use flux in ESMs should be reported as instantaneous emissions, or also account for delayed carbon responses and regrowth. These differences explain a factor 2-6 difference between model estimates and are expected to be further affected by interactions with land management. This highlights the importance of an accurate protocol for future model intercomparisons of carbon fluxes from land cover change and land management to ensure comparison of the same processes and fluxes.