Project: **891**
Project title: **Forest management in the Earth system**
Principal investigator: **Julia Pongratz**
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1. Introduction

The main aim of this project is to better understand the role of land use for and in a changing climate. Land use affects about three quarters of the ice-free land surface. One previously often neglected form of land use – land management (such as forestry harvest) – has been increasingly identified to matter substantially for climate and biogeochemical cycles even on global scale. The importance of land based mitigation and adaptation to climate change contributes to this increase in awareness. Our group therefore fosters the development of the MPI Earth system model, as well as of the ICON model, towards including land management practices and required structural land representations to better understand and quantify the human impact on the Earth system (see sections 3 to 6). But it also deals with fundamental gaps in our process understanding in general (section 2, 3, 5 and 6). We report here on the progress of the projects proposed in the request for DKRZ resources for 2020.

2. Drought response feedback

The Amazon forests are one of the largest ecosystem carbon pools on Earth. Climate projections predict more frequent and prolonged droughts in many places of the world including the Amazon basin (Joetzjer et al., 2013). However, most vegetation models are currently unable to capture observed drought responses of forests (Powell et al., 2013, Joetzjer et al., 2014). In the 2019 part of the project we conducted development in JSBACH tuning soil moisture and LAI responses to soil moisture and incorporating new formulations of leaf phenology, litter production and tree mortality, all based on intensive field measurement of a wide range of variables from the throughfall exclusion (TFE) experiments performed in the Amazon (Nepstad et al., 2006, Fisher et al., 2007). We conducted simulations with the improved MPI-ESM to quantify the climate feedback of future direct (soil drying) and LAI (leaf shedding) effects separately. In 2020, further ensemble simulations were conducted with both the standard and modified model versions. We are thus able to quantify the uncertainty associated with internal variability and leaf shedding formulation, respectively. It is found that the leaf shedding plays an important role in reducing future carbon uptake in the Amazon. Meanwhile, the model uncertainty associated with leaf shedding is large for carbon budgets (Fig. 1; Wey et al., in prep.).

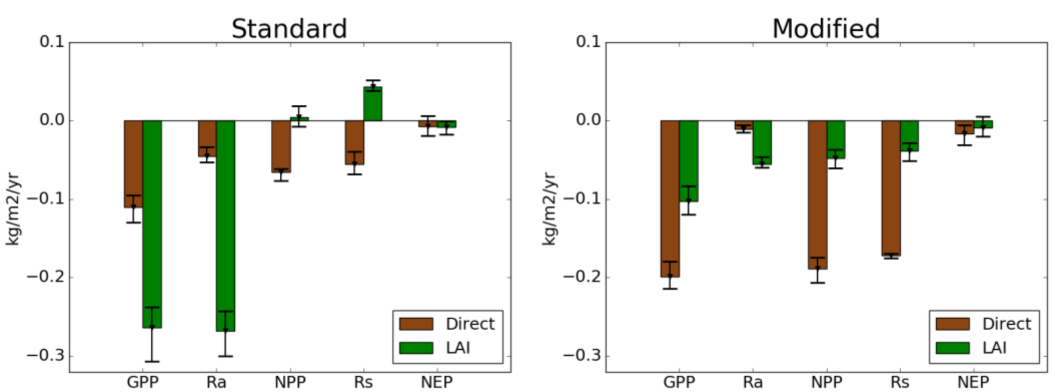

Fig 1. The comparison of the direct and LAI drought effects on carbon budgets simulated by the standard and modified JSBACH in the Amazon forests during 2071–2085 under RCP8.5 scenario. Bars represent ensemble means and whiskers represent range of ensemble members. Ra: Autotrophic respiration. Rs: Soil respiration.

3. Anthropogenic carbon budget in the Grand Ensemble (GE)

We finished the large ensemble of additional CBALONE simulations required to separate out land-use change effects on the carbon cycle. With these, we can split the net carbon fluxes in the GE into the 5 components also provided by the Global Carbon Project's annual carbon budget (Friedlingstein et al., 2019), namely land-use change emissions, fossil emissions (as an implied term, i.e. residual of the other 4 terms, in the GE), natural sink on land, natural sink in the ocean, and atmospheric growth rate (prescribed in GE) (Fig. 2 left; Loughran et al., in prep.). We found the following:

1) Largest internal climate variability of all MPI-GE budget terms is from the land sink (±1.5PgC/yr) which increases in RCP4.5.
2) Largest differences between MPI-GE and GCP decadal averages are found for land-use emissions, due to RCP4.5 assuming re-/afforestation that actual policies have not followed (Fig. 2 right).
3) The likelihood of historical carbon fluxes has fluctuated high and low throughout history, which is at least partially related to ENSO.

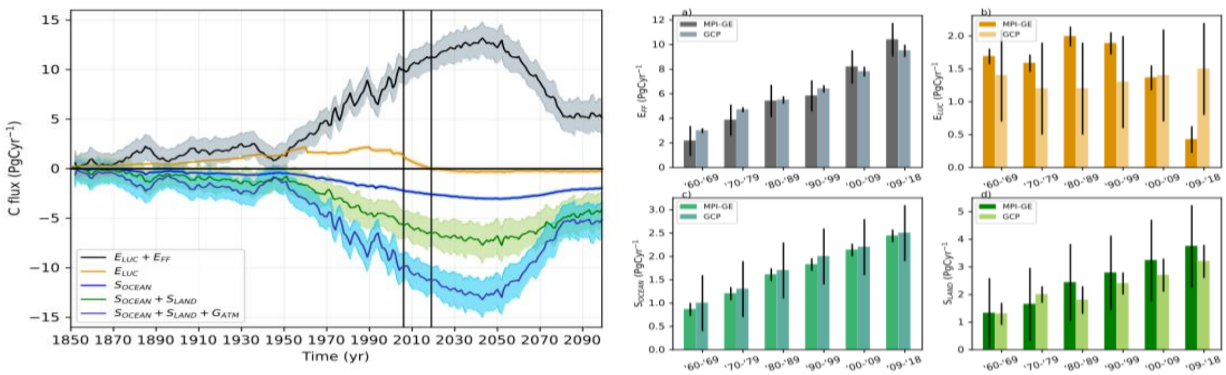

Fig. 2: Stacked MPI-Grand Ensemble carbon budget terms and ±1σ ranges (left) and comparison to the Global Carbon Project's annual carbon budget (right).

4. Towards application simulations with the forest age structure

Land use, particularly de- and reforestation and forest management, alter the forest age structure. Although biogeochemical as well as biophysical effects of such structural changes are known to be strong (Erb et al., 2016), many land surface models, such as JSBACH, neglect age effects (Pongratz et al., 2017) and assume ageless or mean-age forests. One important reason for this simplification is the increase in computational complexity when introducing cohorts/forest age-classes as new land cover tiles, because many of the represented processes, such as photosynthesis and respiration, are calculated per land cover tile. Moreover, in models with a flat tile hierarchy, such as JSBACH3, the introduction of age-classes would be computationally inefficient since it would require a multiplication of properties common to the represented forest plant functional types (PFT). In contrast to JSBACH3, JSBACH4 provides a hierarchical tile structure enabling a common treatment of age-classes of the same forest PFT where appropriate.

In the allocation period 2018, we implemented forest age-classes in JSBACH4.2 (Nabel et al., 2018, 2020). In 2019 we conducted JSBACH4 standalone simulations with different numbers of age-classes and age-class distribution schemes, and evaluated the outcomes with observational-based data to determine a trade-off between accuracy and computation complexity. Introducing age-classes improved the comparison to observation-based data. Improvements saturated with the number of applied age-classes, while computation costs linearly increased. This work has meanwhile been published (Nabel et al., 2020). In 2018, 2019 and in the current period we conducted test-simulations with JSBACH4 standalone, as well as JSBACH4 in ECHAM6-AMIP and ICON-AMIP. As reported before, ICON-AMIP and ECHAM6-AMIP test simulations with JSBACH4 revealed higher than expected costs and various infrastructural problems in simulations with and without forest age structure, which we contributed to solve and are still working on (e.g. transferring the equilibration script from JSBACH3.2 to JSBACH4). Overall, delays in the general development of ICON/JSBACH4 and of presupposed applications with this model in other projects (suitable carbon equilibrium not yet available; land-use transitions not yet implemented; still no common infrastructure for processes applying area changes) prevented planned productive applications.

5. LUMIP simulations

The land use model intercomparison project is an endorsed MIP of CMIP6, co-chaired by J. Pongratz and V. Brovkin. Within LUMIP, several model setups are proposed for simulations of the past and future influence of land-use change on climate and the carbon cycle. While coupled simulations have been performed over the last few years, offline simulations were still missing. These are factorial simulations that are meant to identify sensitivity of near-surface climate and biogeochemical fluxes towards starting date, alternative land-use forcings, but foremost also towards inclusion or exclusion of land management such as wood harvesting or shifting cultivation. Such land management has been shown to be potentially very relevant e.g. for CO_2 emissions from land-use change, altering them up to 100% in some models (Arneth et al., 2017); however, a large MIP has so far been missing. We performed these JSBACH offline simulations and added their CMORized data to the ESGF nodes.

6. Participation in TRENDY

In this allocation period JSBACH has again participated in the long-standing MIP of the Global Carbon Project, TRENDY ("Trends in the global carbon cycle"), which delivers annual updates of the global carbon budget (Friedlingstein et al. 2019, subm.). TRENDY simulations are not only used in the global carbon budget, but also in the framework of the REgional Carbon Cycle Assessment and Processes (RECCAP; e.g. Bastos et al. 2020) and for other further reaching studies, e.g. the identification of the causes of slowing-down seasonal CO_2 amplitude at Mauna Loa (Wang et al., 2020), or comparison to / cross-consistency checks with observational data (Pan et al., 2020; Yang et al., 2020; Collalti et al., in press).

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