Project: **891**
Project title: **Forest management in the Earth system**
Principal investigator: **Julia Pongratz**
Report period: **2019-01-01 to 2019-12-31**

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. 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 4 and 5). But it also deals with fundamental gaps in our process understanding of land use change effects on climate in general (section 2, 3 and 5). We report here on the progress of the projects proposed in the request for DKRZ resources for 2018.

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 (Wey et al. 2018), 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 leaf shedding. Preliminary results show unexpected effects on precipitation, therefore we plan additional simulations to quantify the precipitation effect resulting from outside the Amazon region.

3. Carbon budget variability in the MPI-ESM grand ensemble

The MPI-ESM grand ensemble (GE) offers a unique chance to investigate the variability of carbon fluxes and to test how well the MPI-ESM captures the observed and projected carbon cycle dynamics under climate change. We reconstruct the historical global carbon budget using the same terms as the annual global carbon budget by the Global Carbon Project (J. Pongratz is lead of the land use emissions in GCP's budget). However, the net land-atmosphere exchange is not split into land use emissions and the natural sink in coupled simulations as those of the GE. We therefore performed additional simulations with JSBACH's carbon cycle offline module for each GE ensemble member, excluding land use change, thus isolating the natural land sink. A full split of all budget terms in a large ensemble is unique. It allows us to determine implied fossil-fuel emissions. Analyses are ongoing. First results point to the MPI-ESM being consistent with GCP's historical budget, but having a bias towards higher allowable fossil-fuel emissions compared to the Integrated Assessment Model GCAM, which provided emission and concentration scenarios for RCP4.5 (Loughran et al., 2019).

4. First 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), in 2018 and 2019 we conducted test-simulations with JSBACH4 standalone, as well as JSBACH4 in ECHAM6-AMIP and ICON-AMIP. As reported last year, 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. Overall, delays in the general development of ICON/JSBACH4 and of presupposed applications with this model in other projects (still no suitable carbon equilibrium available) prevented productive ICON-AMIP applications. As reported before, we therefore used JSBACH4 standalone instead of the ICON-AMIP setup for the first application with forest age structure. In 2018 and 2019, we conducted simulations with different numbers of age-classes and age-class distribution schemes, and evaluated the outcomes with global observations of gross primary production (GPP), leaf area index (LAI) and above-ground biomass (AGB), to determine a sensible trade-off between accuracy and computation complexity. Introducing age-classes improved the comparison to observation-based data for nearly all compared variables, regions and seasons. Improvements saturated with the number of applied age-classes, while computation costs linearly increased (Fig. 1), pointing towards an optimal number of age-classes depending on the targeted application. This work has been published as a discussion paper (Nabel et al., 2019).

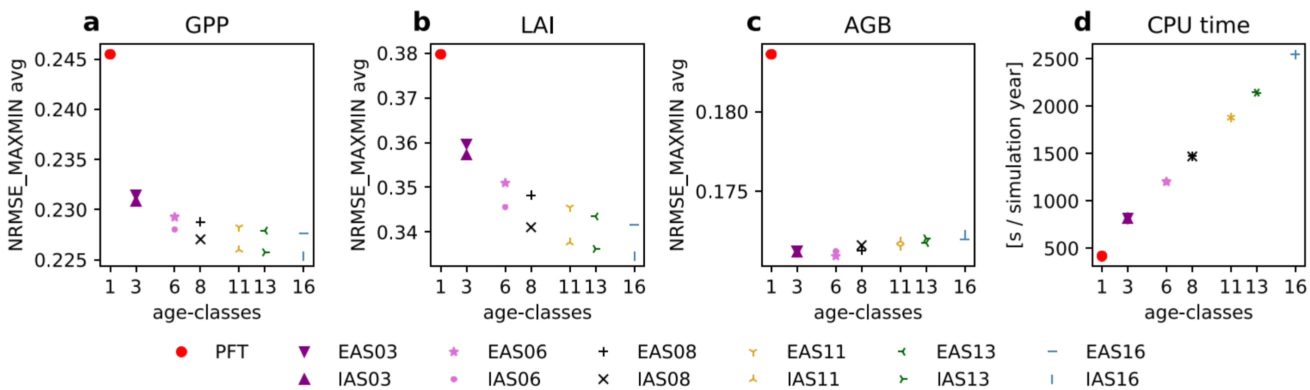

Figure 1. Change in NRMSE Max-Min and CPU time when increasing the number of age-classes.

5. 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 (Le Quéré et al., 2018; Friedlingstein et al., subm.). TRENDY simulations are not only used in the global carbon budget, but also for further reaching studies, e.g. the identification of the drivers of northern high latitudinal increase in the amplitude of seasonal CO_2-cycle exchange (Bastos et al., 2019), or comparison to / cross-consistency checks with observational data (Jung et al., 2019; Yuan et al., 2019; Forzieri et al., in press).

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