Project: **891**
Project title: **Forest management in the Earth system**
Principal investigator: **Julia Pongratz**
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The scientific work under bm0891 during the reporting period focused on a more profound understanding and better quantification of land-related carbon fluxes, applying process-based (JSBACH) and bookkeeping models (BLUE), and droughts.

TRENDYv11: For participation in the Global Carbon Budget 2022, simulations with JSBACH3 were conducted in accordance with the TRENDY protocol, for the first time on levante. Branching off of MPI-ESM-landveg (rev `c983709`), the model was extended by PFT-level output following the previous work in Friedlingstein et al. (2022). The protocol specifies a target accuracy of the equilibrium state for both global carbon and nitrogen. Starting from the TRENDYv10 equilibrium state the model was integrated for a total of 2000 years. Land cover has been kept constant at 1700 values and climate (CRUJRAv2.3, 2022) was recycled in accordance with the protocol. Four experiments (4x220 years) were conducted branching off this spin-up. Both land-use change (LUH2) and climate data have been downloaded in 0.5deg resolution and pre-processed for JSBACH3 in T63 resolution. Post-processing included computation of monthly means, cmorizing, and extraction of zonal total carbon. Jupyter-hub was used to monitor and visualize the progress of the model integrations and results. Results were submitted at the beginning of September. The Global Carbon Budget 2022 will be presented by the PI at the COP27. During the last year, further spin-off studies were conducted on earlier years' TRENDY simulations, which we had also participated in, e.g. an analysis of regional carbon fluxes for Southeast Asia (Kondo et al. 2022) or an analyses of key uncertainties in land carbon fluxes (O'Sullivan et al. 2022).

BLUE: We have contributed simulations with our bookkeeping model BLUE to the Global Carbon Budget 2022 (Friedlingstein et al. 2022). They have been used in a range of follow-up studies by our and other groups, including the upcoming UNEP emission gap report (Lamb et al., subm.), studies linking the global carbon cycle models' estimates of land-use change emissions to those reported by countries under UNFCCC (Grassi et al., 2022; Schwingshackl et al., subm.), and a study using atmospheric CO_2 levels to constrain land carbon fluxes (Dohner et al. 2022).

A new high-resolution land-use and land cover change (LULCC) dataset (HILDA+) was implemented in the bookkeeping model BLUE and the results compared to estimates from simulations based on LUH2 (Chini et al., 2021), which is the LULCC dataset most commonly used in global carbon cycle models, e.g. in the Global Carbon Budget or CMIP6. Compared to LUH2-based estimates, results based on HILDA+ show lower total land-use emissions (global mean difference 1960–2019: 541 TgC yr^{-1}, 65%) and large spatial and temporal differences in component fluxes (e.g. CO_2 fluxes from deforestation). In general, the congruence of component fluxes is higher in the mid-latitudes compared to tropical and subtropical regions, which is to some degree explained by the different implementations of shifting cultivation in the underlying LULCC datasets. Globally and in many regions, land-use emission estimates based on HILDA+ have decreasing trends, whereas estimates based on LUH2 indicate an increase. Furthermore, the effect of different resolutions on land-use emission estimates were analyzed. Comparing estimates from simulations at 0.01° and 0.25° resolution, component fluxes of estimates based on the coarser resolution tend to be larger compared to estimates based on the finer resolution, both in terms of sources and sinks (global mean difference 1960–2019: 36 TgC yr^{-1}, 96%). The reason for these differences was identified to be successive transitions: these are not adequately represented at coarser resolution, which has the effect that—despite capturing the same extent of transition areas - overall less area remains pristine at the coarser resolution compared to the finer resolution. The study was published in ERL (Ganzenmüller et al., 2022); the simulation results contributed to follow-up studies on regional scale (Winkler et al., subm.) or that established a protocol for the regional carbon assessment RECCAP-2 (Ciais et al., 2022).

We implemented improved parameterisations of slash, wood product pools and product pool response curves in BLUE and compared the results to the default model version (Nützel et al., in prep.). Globally, emission differences due to the modifications are low (-2.3% to default over full simulation period, 1700 to 2019; -3.1% to default over last 20 years). The low global emission differences are due to compensation of stronger regional differences in temperate/boreal regions by low regional differences in the tropics. Considering the latitudinal mean difference of t95 (the time at which 95% of C in wood/soil decayed) after harvest on secondary land over the full simulation period, in the simulation with all modifications C is stored 3 to 34 years longer in soil or products before reaching the atmosphere north of 30° N and south of 30° S, while it is stored only up to 4 years longer and in parts even up to 1 year shorter in the tropics. Same holds after clearing on secondary land, where C is stored 3 to 27 years longer in soil or products before reaching the atmosphere north of 30° N and south of 30° S and only 1 to 6 years longer in between. Slash modifications can explain by far most of the global emission difference (56.9% during the full simulation period; 72.2% over the last 20 years), followed by the new product pool response curves (26.2% over the full simulation period; 9.7% over the last 20 years) and the product pool modifications (16.9% over the full simulation period and 18.0% over the last 20 years). We assess the uncertainty of LULCC emissions on the chosen parameter modifications: Even with strongly differing slash fractions impact on LULCC emissions is low, while it is higher for alternative product pool setups. Sensitivity simulations assuming all wood product carbon in BLUE to be used in long-living products and globally applying high soil time constants lead to substantial emission reductions especially in the tropics, but are still in the uncertainty range of the Global Carbon Budget. The product pool and slash modifications of this study can serve as an example to better represent slash and wood products in more process-based models (e.g. DGVMs or ESMs).

Drought studies: Droughts are predicted to enhance in the Amazon forests under future climate. Hoever, the vegetation responses to drought simulated by most vegetation models deviate from observations. In the study, we modify the vegetation model JSBACH. By comparing against the MODIS LAI product, we show that the modification improves the model. We then assess the future drought effects under RCP8.5 scenario, and the roles of canopy response (LAI effect) and soil moisture are separated. The LAI effect accounts for 35% in reducing land carbon uptake, and 12% in increasing surface temperature. We show that for the drought effects on carbon budget terms, model uncertainty (associated with the formulations of LAI) is larger than internal variability, while for biogeophysical terms the internal variability is more important. The results are published in JGR: Biogeosciences. We participated in a model intercomparison project for investigating the vegetation responses to drought and heat stresses. Different combinations of drought and heat stresses including drought-only, heat-only, and drought-heat-combined are applied to several vegetation models including JSBACH to understand how different models simulate the vegetation response to extreme events. Preliminary results show that the model uncertainty range is large. The expected publication is titled "Large variability in simulated response of vegetation composition and carbon dynamics to variations in drought-heat occurrence", and will be submitted to JGR: Biogeosciences.