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Climate-induced hysteresis of the tropical forest in the fire-enabled Earth system model CM2Mc-LPJmL

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Tropical rainforests are recognized as one of the terrestrial tipping elements which could have profound impacts on the global climate, once their vegetation has transitioned into savanna or grassland states. While several studies investigated the savannization of, e.g., the Amazon rainforest, few studies considered the influence of fire. Fire is expected to potentially shift the savanna-forest boundary and hence impact the dynamical equilibrium between these two possible vegetation states under changing climate. To investigate the climate-induced hysteresis in pan-tropical forests and the impact of fire under future climate conditions, we coupled the well established and comprehensively validated Dynamic Global Vegetation Model LPJmL5.0-FMS to the coupled climate model CM2Mc, which is based on the atmosphere model AM2 and the ocean model MOM5 (CM2Mc-LPJmL v1.0). In CM2Mc, we replaced the simple land surface model LaD with LPJmL and fully coupled the water and energy cycles. Exchanging LaD by LPJmL, and therefore switching from a static and prescribed vegetation to a dynamic vegetation, allows us to model important biosphere processes, including wildfire, tree mortality, permafrost, hydrological cycling, and the impacts of managed land (crop growth and irrigation).

With CM2Mc-LPJmL we conducted simulation experiments where atmospheric CO₂ concentrations increased from a pre-industrial level up to 1280 ppm (impact phase) followed by a recovery phase where CO₂ concentrations reach pre-industrial levels again. This experiment is performed with and without allowing for wildfires. We find a hysteresis of the biomass and vegetation cover in tropical forest systems, with a strong regional heterogeneity. After biomass loss along increasing atmospheric CO₂ concentrations and accompanied mean surface temperature increase of about 4°C (impact phase), the system does not recover completely into its original state on its return path, even though atmospheric CO₂ concentrations return to their original state. While not detecting large-scale tipping points, our results show a climate-induced hysteresis in tropical forest and lagged responses in forest recovery after the climate has returned to its original state. Wildfires slightly widen the climate-induced hysteresis in tropical forests and lead to a lagged

response in forest recovery by ca. 30 years.