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Fire prevents the regrowth of the Amazon rainforest after complete deforestation in a fire-enabled Earth system model

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Overview

Anthropogenic climate and land-use change profoundly impact the terrestrial biosphere, which not only affects vegetation dynamics, but also changes **land-atmosphere feedbacks**.
In particular, tropical rain forests, such as the Amazon, are endangered by anthropogenic activities and are recognized as one of the terrestrial **tipping elements**. An ecosystem regime change to a new state could have profound impacts on the global climate, once the biome has transitioned from a forest into a savanna or grassland state.
Fire could potentially shift the **savanna-forest boundary** and hence impact the dynamical equilibrium between these two possible vegetation states under a changing climate.

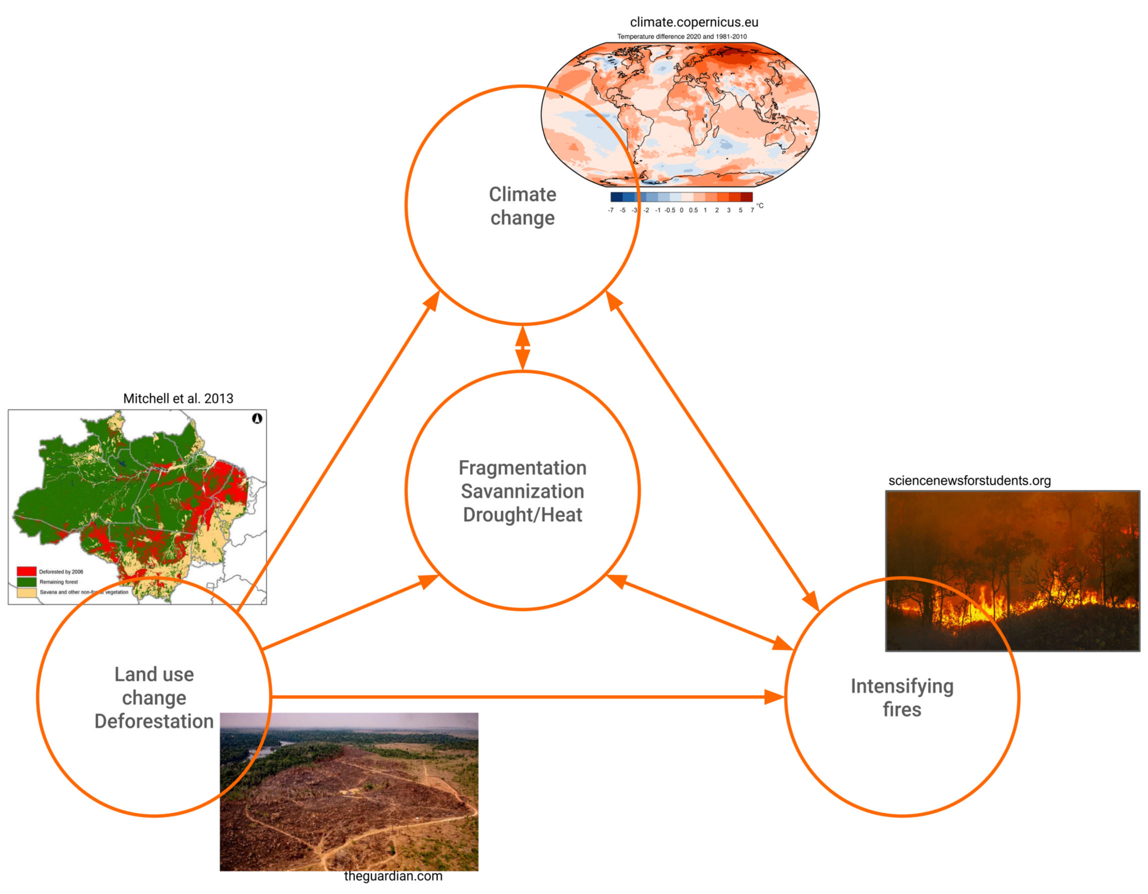

Fig 1: Interactions between climate change, deforestation and fire might cause the Amazon rainforest to shift into a savanna or grassland state.

The Earth system model CM2Mc-LPJmL

The coupled **Earth system model** CM2Mc-LPJmL v1.0 (Drüke et al. 2021) combines the coarse-grained but relatively fast atmosphere and ocean model CM2Mc (Galbraith et al. 2011) with the state-of-the-art dynamic global vegetation model (DGVM) LPJmL5 (Schaphoff et al. 2018a and b, von Bloh et al. 2018). LPJmL5 simulates important biophysical coupling variables as surface temperature, humidity, albedo and roughness length.

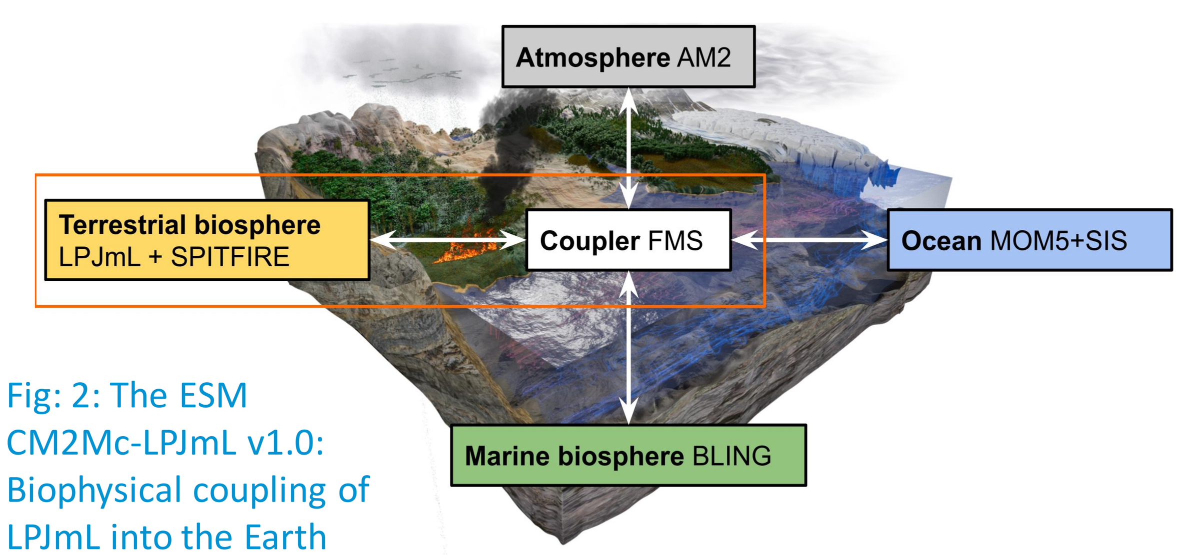

Fig: 2: The ESM CM2Mc-LPJmL v1.0: Biophysical coupling of LPJmL into the Earth system model CM2Mc from GFDL.

Simulation protocol

The aim of this study is to investigate the impact of fire on a potential **recovery** of the Amazon rainforest after large-scale deforestation.

Two step simulation setup after climate, vegetation and fire are brought into equilibrium:

1. **Grassland phase: Complete deforestation** of the Amazon rainforest, while only grasses can establish and grow for a period of **250 years.**
2. **Recovery phase**: For a second period of **250 years**, trees can establish and **grow back.**

Both simulation steps were performed for constant atmospheric CO_2 levels of 284, 450, 750 and 1200 ppm, each of them with fire disturbance **enabled** and **disabled**. For all experiments a control simulation was performed without deforestation.

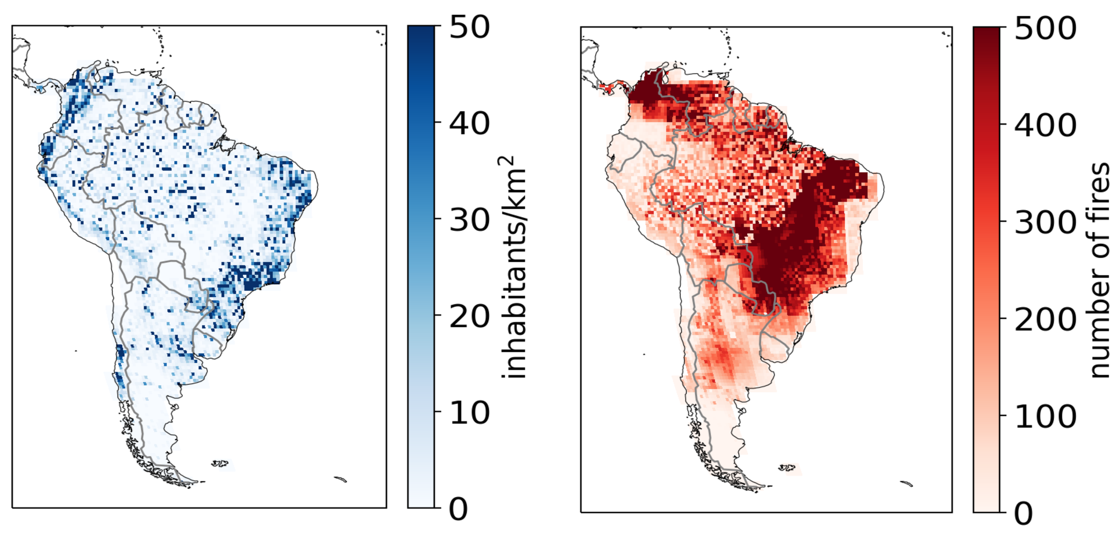

Fig. 3: Effect of human-caused fires. Spatial pattern of population density as input (left) and resulting number of fires in the 750 ppm deforestation experiment (right).

Each grid-cell in the Amazon was assigned the **population density** of a random cell in the Cerrado (Savanna region neighbouring the Amazon) and the average lightning flashes from the Caatinga (dry region in north-east Brazil). Both inputs have been used for each simulation experiment, including the control experiments.

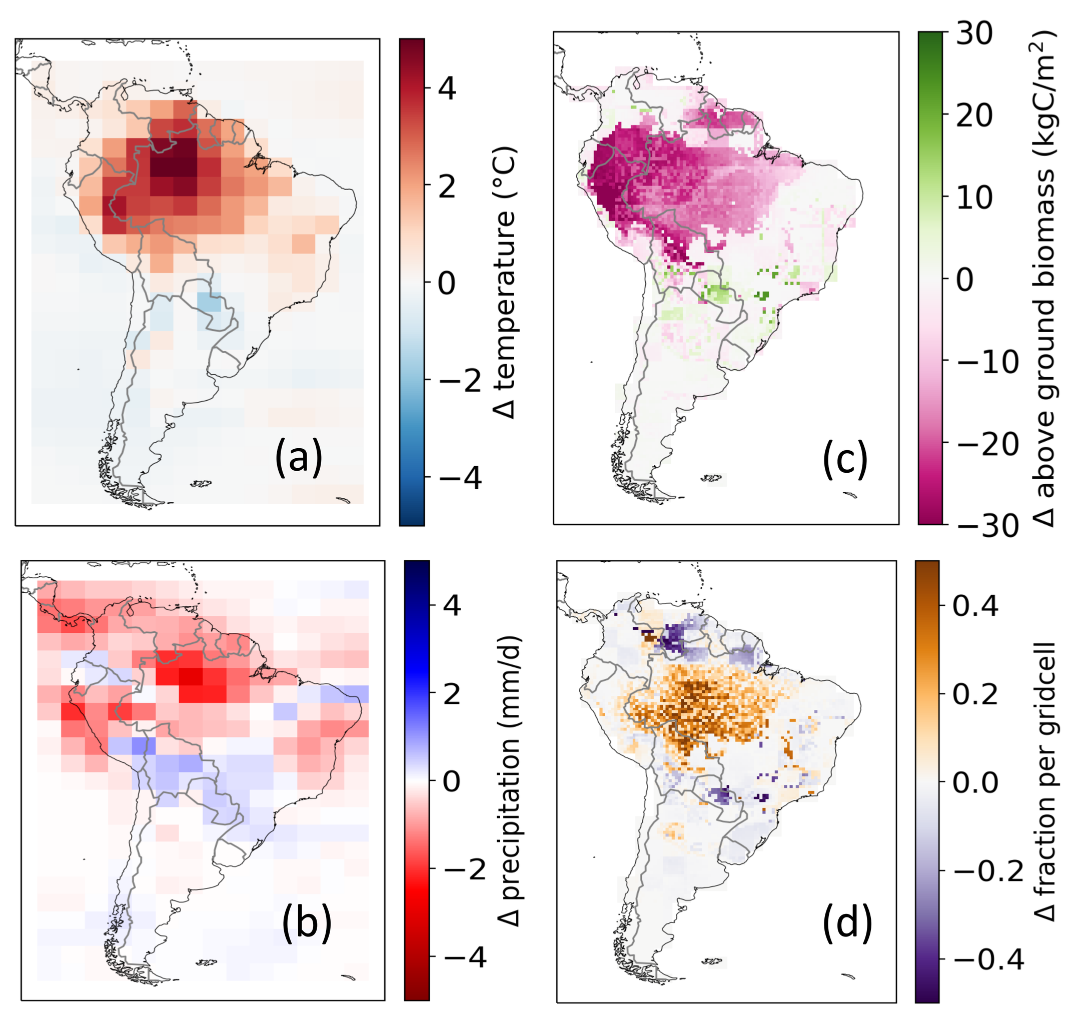

Fig. 4: Difference between the last 10 years of the 750 ppm Grassland phase and the 750 ppm control run (experiment – control) for temperature (a), precipitation (b), biomass (c) and burnt area (d).

Results

In the first phase of the experiment, **biophysical feedbacks** caused a decrease in evapotranspiration, humidity, precipitation and evaporative cooling, therefore to warming (ca. 4° C) in the grassland state. These changes in land-surface & climate conditions also increased fire activity (Fig. 4).

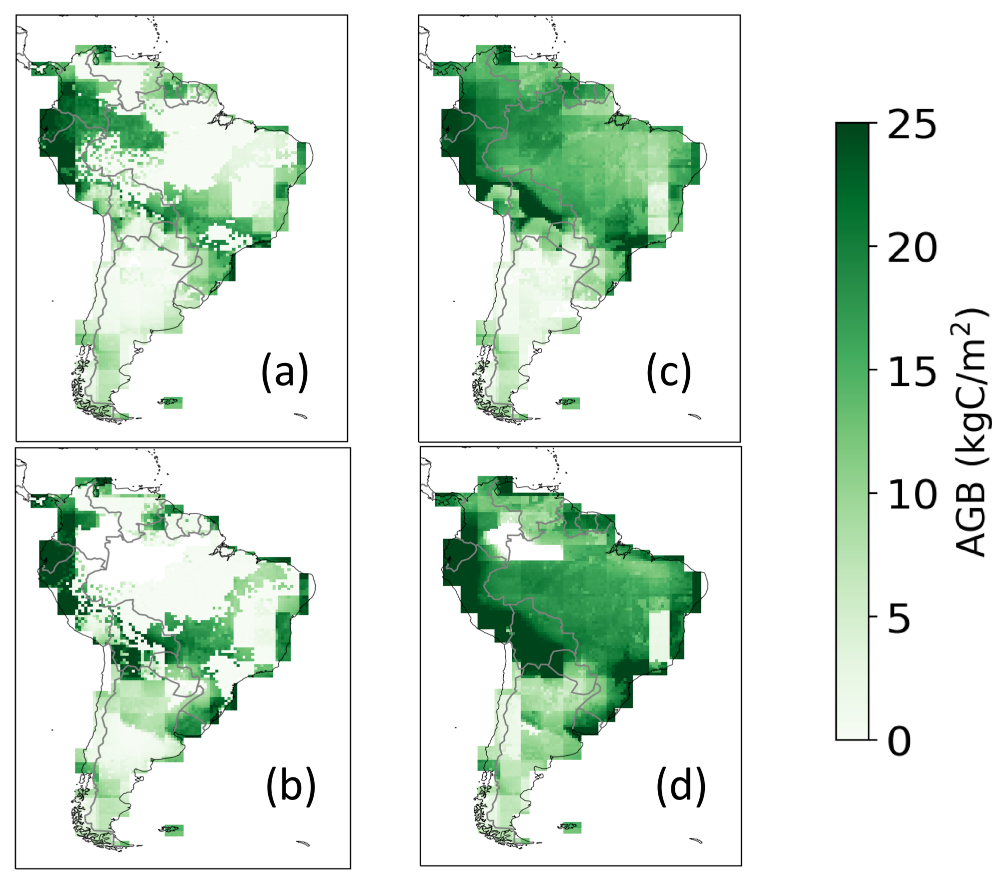

Fig. 5: Vegetation biomass of South America for the last 10 years of the recovery phase for the experiments with fire at 450 ppm (a), with fire at 1200 ppm (b), without fire at 450 ppm (c) and without fire at 1200 ppm (d).

After the Recovery phase, the Amazon rainforest was able to recover almost completely in all experiments without fire disturbance. Only at 1200 ppm, a small area of grassland remained (Fig. 5d). In the experiments with fire disturbance enabled, only a small part in western Amazon was able to recover back to a full forest state (Fig. 5a and b).

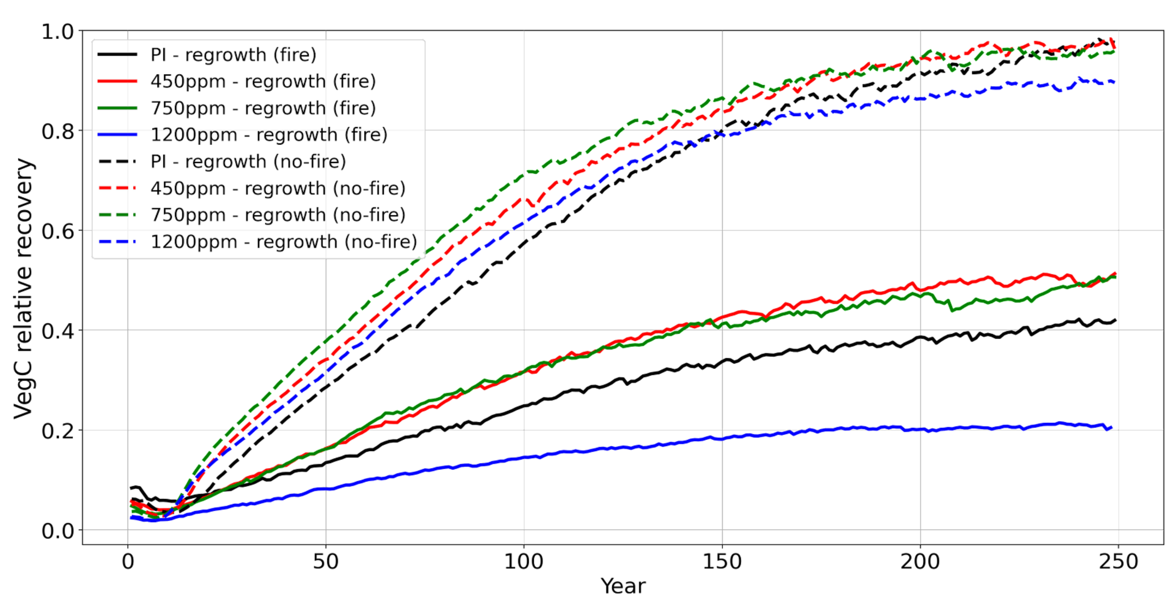

Fig. 6: Time series of the recovering biomass during the Recovery phase for experiments with (solid lines) and without fire disturbance (dashed) relative to their control experiment (Amazon average). Without fire, the Amazon rainforest recovered almost 100 % of its original biomass, while fire strongly disturbed biomass recovery.

Conclusion

Applying the ESM CM2Mc-LPJmL, we showed that fire led to a **lock-in effect** in the **grassland state and drier climate** after large-scale deforetation in the Amazon. **Fire** prevented forest recovery and the interaction with **vegetation and climate** caused a **hysteresis** in the recovery of the Amazon and a shift to a **new stable grassland state**.

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Drüke, M., von Bloh, W., Petri, S., Sakschewski, B., Schaphoff, S., Forkel, M., Huiskamp, W., Feulner, G., and Thonicke, K. (2021): CM2Mc-LPJmL v1.0: biophysical coupling of a process-based dynamic vegetation model with managed land to a general circulation model, Geosci. Model Dev., 14, 4117–4141.

Drüke, M., von Bloh, W., Sakschewski, B., Wunderling, N., Petri, S., Cardoso, M., Barbosa, H. M. J., Thonicke, K. (2021). Climate-induced hysteresis of the tropical forest in a fire-enabled Earth system model. Eur. Phys. J. Spec. Top.

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