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

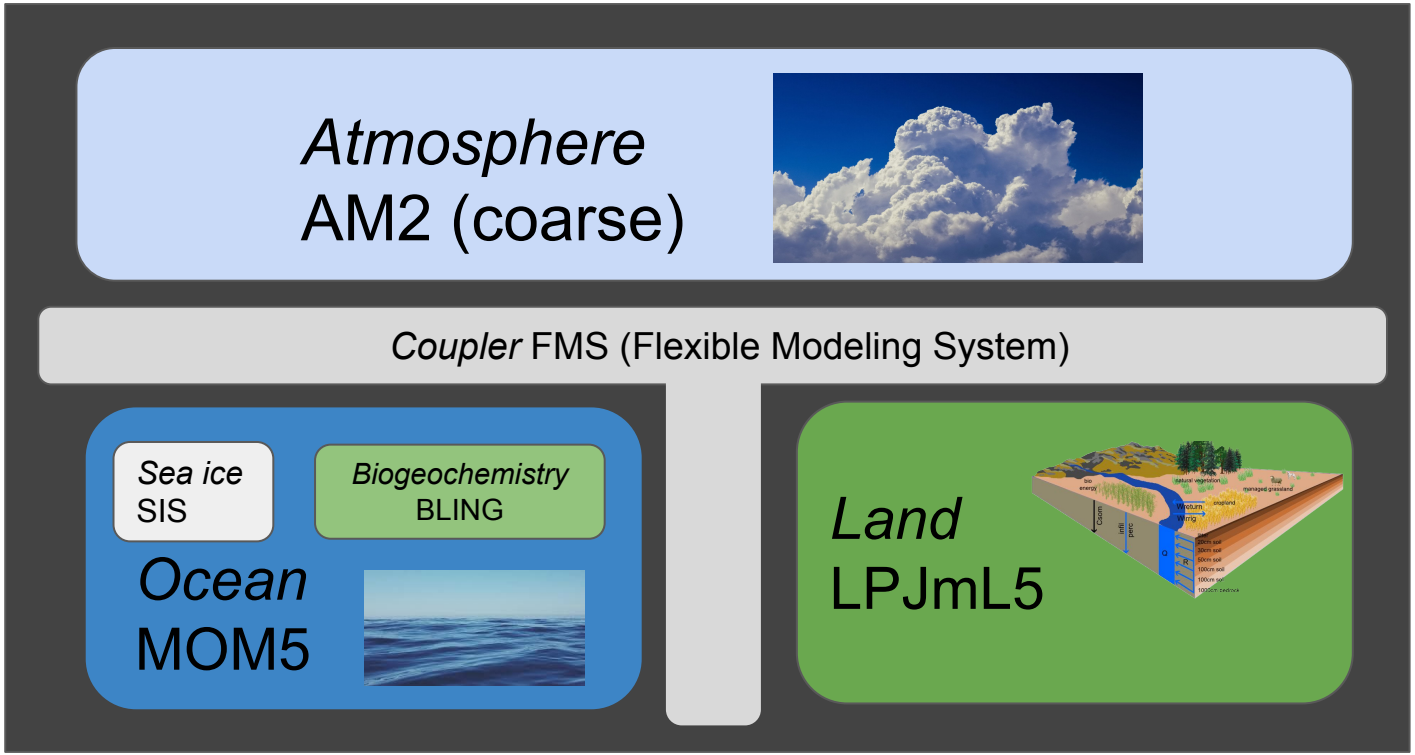
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Drüke et al., European Physical Journal Special Topics, in press (2021)

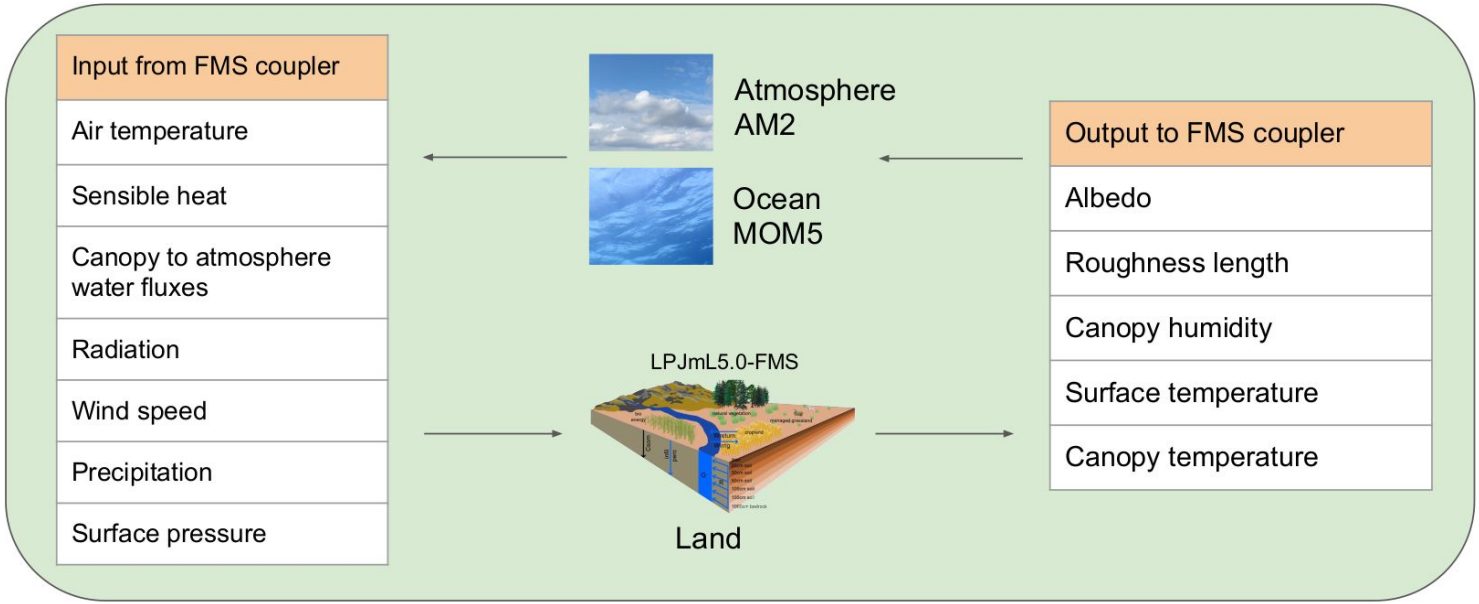
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The Earth system model CM2Mc-LPJmL v1.0



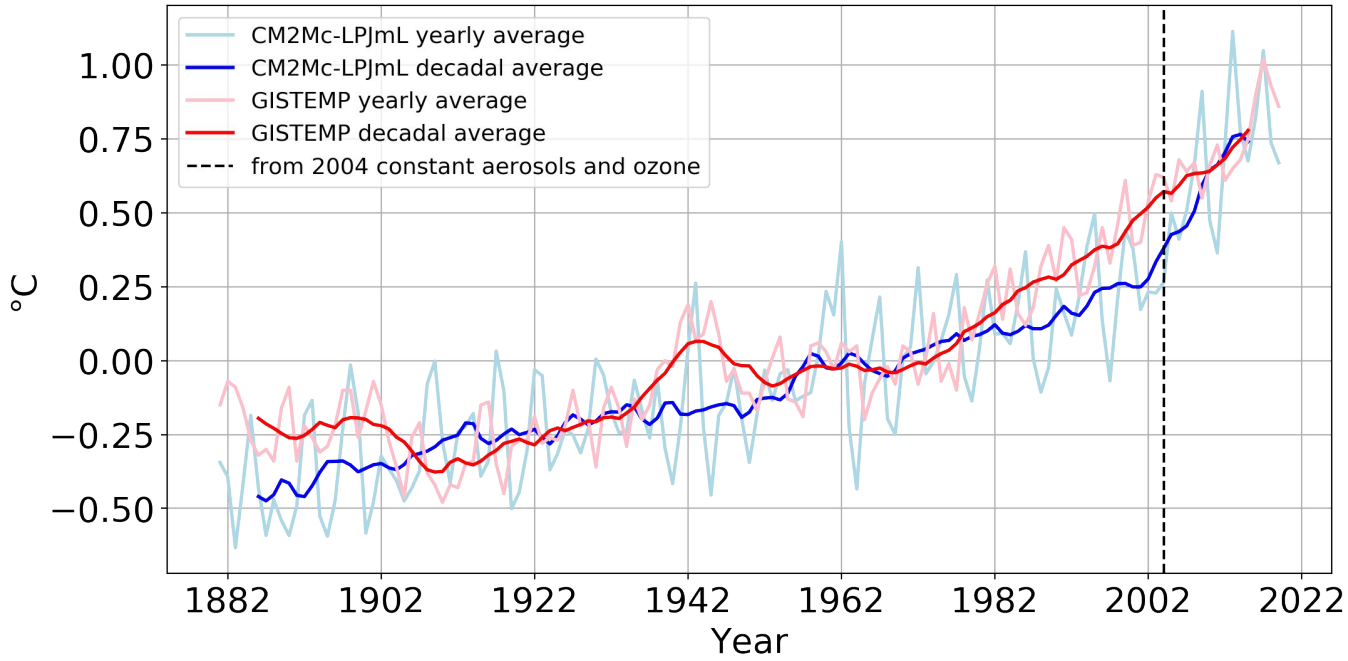
Geophysical Fluid Dynamics Laboratory (NOAA) / PIK Potsdam

Coupling scheme of CM2Mc-LPJmL



Drüke, M., von Bloh, W., Petri, S., Sakschewski, B., Schaphoff, S., Forkel, M., Huiskamp, W., Feulner, G., and Thonicke, K.: CM2Mc-LPJmL v1.0: Biophysical coupling of a process-based dynamic vegetation model with managed land to a general circulation model, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2020-436, in review, 2021.

Historic temperature evolution



Global mean anomaly temperature 1880-2018 (ref. period 1951-1980) compared to GISTEMP

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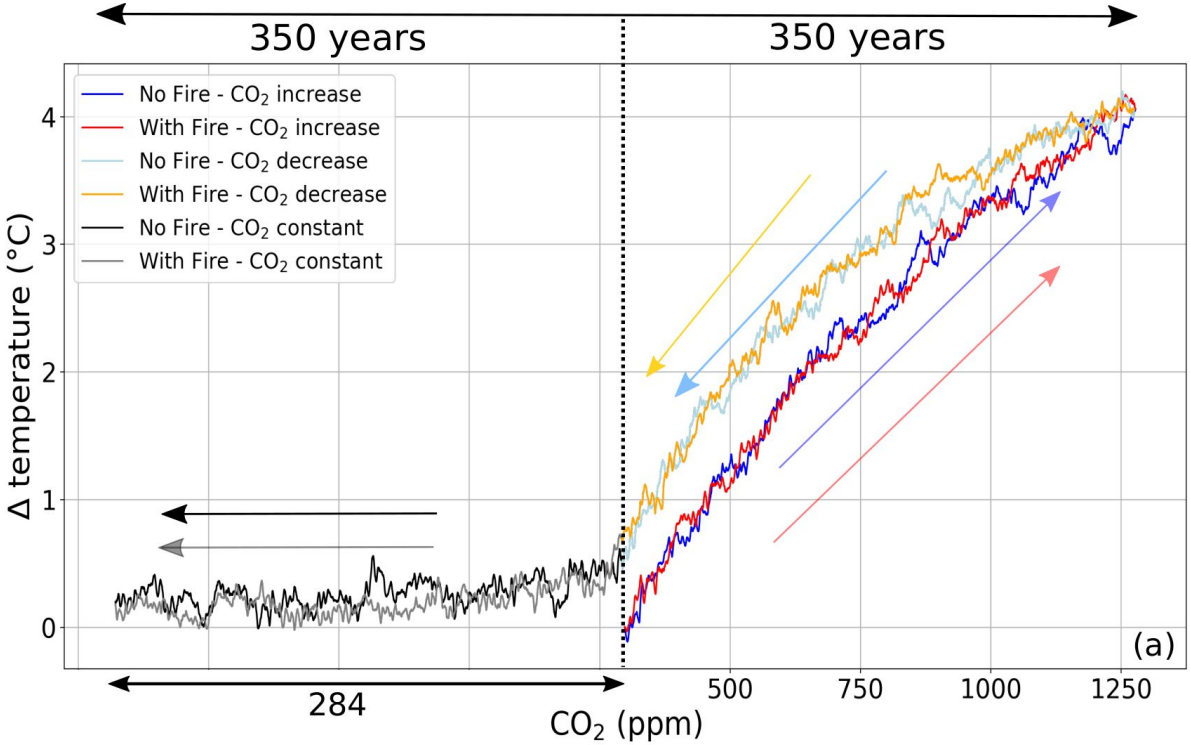
Modeling protocol to investigate a tropical hysteresis

1. **Impact phase:** Linear increase of atmospheric CO_2 level by 1% (from 284 ppm) per year, starting from pre-industrial conditions at 284 ppm over 350 years, reaching a final CO_2 level of 1280 ppm.
2. **Recovery phase:** Subsequent linear CO_2 decrease, according to the impact phase, reaching 284 ppm after 350 simulation years.
3. **Post-recovery phase:** 350 additional years with constant CO_2 at 284 ppm to establish the experiment closer to an equilibrium state.

All experiments were performed once with fire and once without fire disturbance and included a respective preceding fully coupled spinup at preindustrial conditions of 500 years.
Land use and CO_2 fertilization effect were turned off to focus on the climatic response of elevated CO_2 concentrations on natural vegetation.

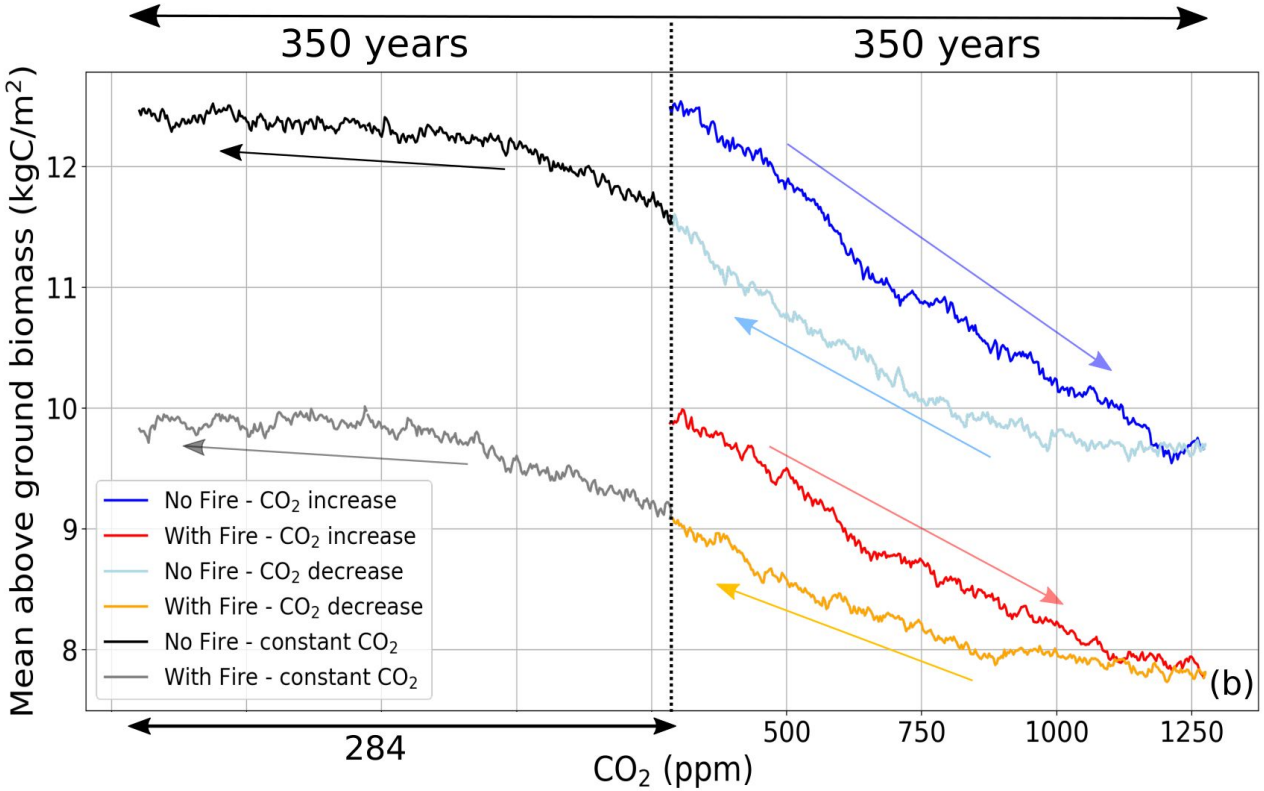
Temperature evolution for the experiment

Overview of tropical mean land surface temperature for the simulation experiments. Atmospheric CO_2 is increasing from 284 ppm to 1280 ppm in 350 years, leading towarming of 4.1 °C in the no-fire (blue line) as well as fire-enabled (red line) experiments, respectively. In the recovery phase experiments, CO_2, and hence tropical surface temperature, decreases again for another 350 simulation years (fire-enabled - orange line; no-fire light-blue line). Each experiment is then continued for another 350 simulation years under pre-industrial conditions marking the post-recovery phase (fire-enabled - light grey line;no-fire - dark grey line).



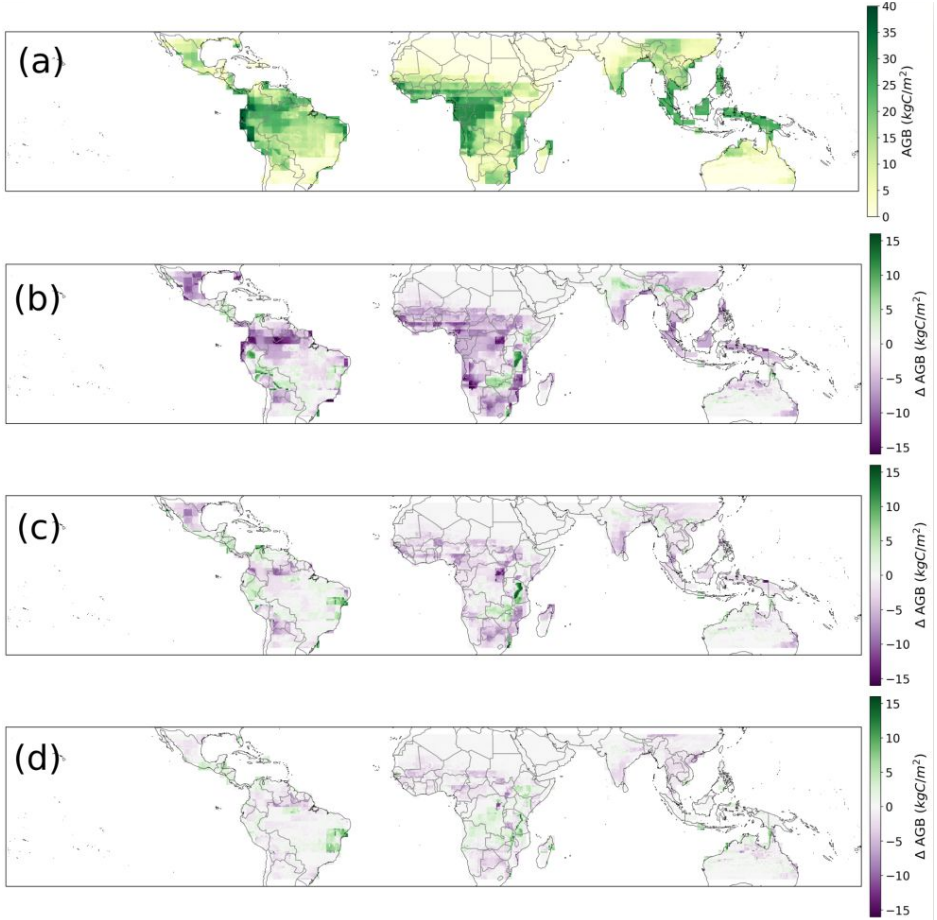
Biomass evolution

Overview of tropical mean above-ground biomass for the simulation experiments. Atmospheric CO_2 is increasing from 284 ppm to 1280 ppm in 350 years, leading to a decrease in biomass of ca. 20% in the no-fire (blue line) and fire-enabled (red line) experiments, respectively. In the reverse experiments, CO_2 decreases again for another 350 simulation years, followed by an increase in biomass (fire-enabled - orange line; no-fire-light blue line). Each experiment is then continued for another 350 simulation years under preindustrial conditions (fire-enabled - light grey line; no-fire - dark grey line).



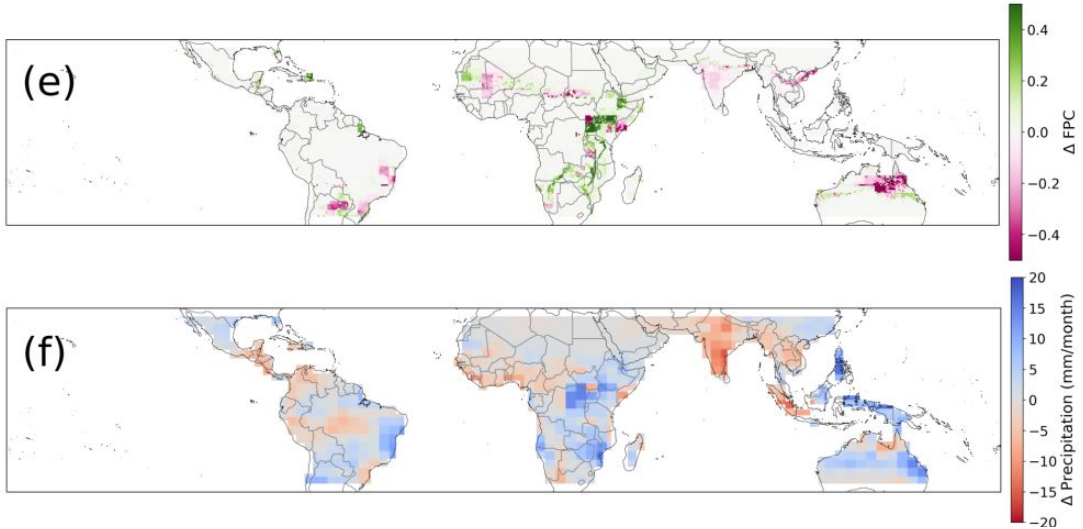
Spatial biomass difference

(a) Simulated above-ground biomass (AGB) at the beginning of the experiments at 284 ppm with fire activated.
(b) Difference between (a) and the end of the impact phase after the first 350 years reaching 1280 ppm.
(c) Difference between (a) and the end of the recovery phase after another 350 years reaching 284 ppm again.
(d) Difference between (a) and after 200 years of the post-recovery phase, after simulating another 200 years under constant CO_2 of 284 ppm.



Tree cover and precipitation differences

(e) Difference of foliar projective cover (FPC) of tropical trees between the beginning of impact phase and the state after 200 years of the post-recovery phase with fire disturbance.
(f) Difference of global precipitation between the beginning of impact phase and the state after 200 years of the post-recovery phase.



Results and Conclusion

- **Observation of a hysteresis in time**: Biomass needed ca. 200 additional years after the recovery phase to reach starting values.
- **Heterogeneous spatial response**: Small regions showed shifts of tree cover and transitioned to an alternate stable state (e.g. to a more grassy environment)
- This shifts went along with **changes in precipitation** patterns and **surface temperature changes**
- However, a large scale tipping point was not observed by using a **biophysically** coupled Earth system model
- Activated fire disturbance leads to a generally lower biomass, but only to a slight further delay of the biomass recovery
- To observe a tropical tipping point probably land use has to be accounted for. In a biophysical coupled model this could lead to a strong climatic response