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Changes to the Earth's energy budget due to global forestation and deforestation affect remote climate via adjusted atmosphere and ocean circulation

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1. Motivation and Simulation set-up

The key motivation for this study is the following: We know that biogeophysical effects of forestation and deforestation change the surface energy balance and have strong remote (similar to "non-local") effects on climate. However, it is unknown how key elements of the atmosphere and ocean circulation are affected and shape this remote climate responses. Here, this open question is addressed using idealized global forestation and deforestation experiments, providing a first basis to assess circulation effects of more realistic scenarios of land-use change in future studies.

Model Version: CESM 2.1.2

Experiments (300 years each):

- *control:* pre-industrial species distribution (forest, grass/crops, shrubs), in equilibrium
- *forest:* only tree species
- *grass*: only grass species

The pre-industrial forest cover and the changes in forest cover for *forest* and *grass* are shown in Fig. 1.

Set-up

- Fully-coupled mode
- pre-industrial (1850) greenhouse gas forcing
- bare soil fraction kept constant
- Species types changed on all natural and crop land
- Relative species distribution within grid box retained (if no species in grid box, use average species distribution of that latitude)

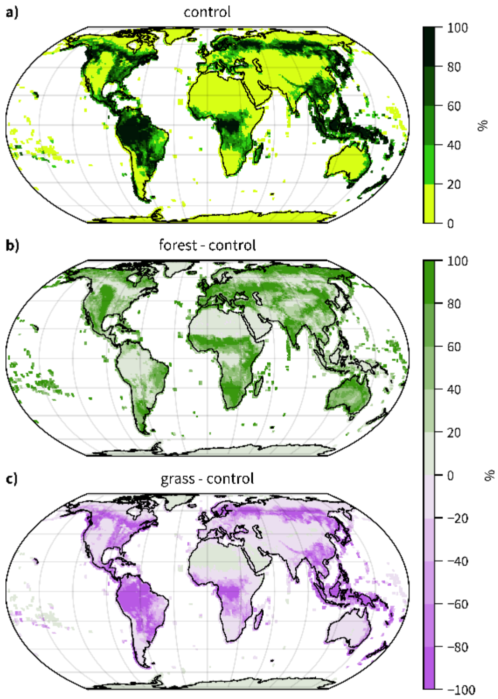

Figure 1: Fraction of land area (shading, in %) that is (a) covered by forest in the control run, (b) forested in the forest run (forest minus control) and (b) deforested in the grass run (grass minus control).

2. Summary of key results

In essence, our analysis shows that, via altering atmospheric temperatures, forestation and deforestation have far-reaching effects on the atmosphere and ocean circulation. Forestation warms the near surface and the whole troposphere over Northern Hemisphere land areas, while deforestation cools it (see Fig.2). These temperature changes are mostly driven by changes in surface short wave forcing (e.g. albedo changes). Hence, forestation reduces the mid-latitude meridional temperature gradient and imposes geopotential height (i.e. circulation) anomalies over land (see Fig. 3). Consequently, zonal mean winds, especially in the mid and upper troposphere (where the jet stream is) weaken (thermal wind balance). The changes in the meridional temperature gradient further change the strength of extratropical weather systems (i.e. cyclones and anticyclones) and shift them poleward in *forest*. The changes in the Earth energy balance also result in changes in meridional heat transport in the climate system. This in turn, leads to changes in intensity of the Hadley cell (the main circulation feature that redistributes heat from the tropics to the subtropics) and shifts the ITCZ in the deforestation scenario. This strongly affects tropical precipitation patterns. However, the largest changes in meridional heat transport occur in the ocean and manifests itself partly as weakening of the Atlantic meridional overturning circulation (AMOC) in forest and a strengthening in grass. This is one of the reasons why the temperature changes over the North Atlantic have a reversed sign than the global mean changes in both scenarios (i.e., a weakening AMOC transports less heat to the North Atlantic, contributing to a cooling there). Overall simulated changes are stronger in the deforestation scenario, mostly because of a strong snow-albedo feedback in the first centuries of the simulation, which is much weaker in grass. Overall, these results suggest that, when designing and evaluating forestation efforts, such effects on circulation and remote climate need to be considered in addition to the biogeochemical and the local/global thermodynamic effects.

Note that this study is likely to be published within a few months and you will find our detailed findings there.

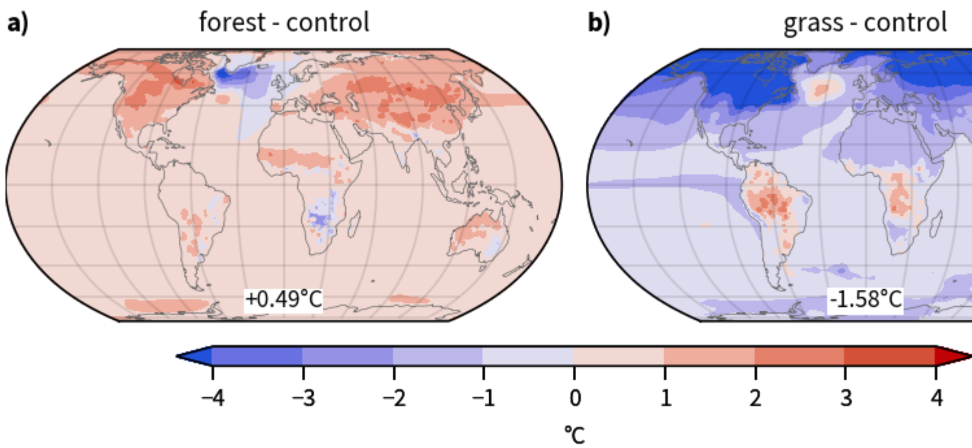

Figure 2: Change of annual mean 2m temperature relative to control for (a) forest and (b) grass (statistically significant),

3. Limitations and outlook

A key limitation is of course that we use only one model and we need to perform similar experiments for different models, to assess the robustness of these results, e.g. of the strong ocean response. Further, the simulated land-use change is very idealized. In a next step, we need to design scenarios that are more realistic. For instance, that include regionally more limited forestation/deforestation and/or their interaction with circulation changes due to greenhouse gas driven global warming.