Modelling vegetation and carbon-cycle feedbacks on climate at different temporal and spatial scales

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The responses of vegetation and carbon-cycle to a changing climate have the potential to act as positive feedbacks, amplifying the initial perturbation. An estimation of the strength of these feedbacks is crucial for the assessment of their contribution to the amplification of future climate change.
In this thesis we use CLIMBER-2, an Earth system model of intermediate complexity, to estimate the magnitude of the vegetation and carbon-cycle feedbacks on the climate. We consider both equilibrium and transient feedbacks. An analysis of the radiative imbalance at the top of the atmosphere caused by changes in vegetation or CO_2 quantifies the vegetation and carbon-cycle feedbacks, respectively, in a manner that makes them directly comparable to the fast climate feedbacks (cloud, water vapour, lapse rate and albedo).
In CLIMBER-2 we include structurally different parameterisations for processes that affect the strength of the feedbacks. Results from this so-called multi-physics ensemble allow us to provide an uncertainty range for our estimates. We estimate the vegetation feedback for a doubling and halving of atmospheric CO_2 relative to the preindustrial value of 280 ppm. The vegetation-climate feedback is globally positive but rather small. However, it is regionally comparable to the fast climate feedbacks in the boreal zone, the Amazon rainforest and the Sahara. There is an asymmetry between warming and cooling, with a larger, positive vegetation-climate feedback in the lower CO_2 climate. This highlights the need for caution when using past glacial climate change to derive Earth system sensitivity applicable for future climate change.
A more appropriate estimate of the Earth system sensitivity that can be expected for future warming can be obtained from warm periods in the past. The most recent period that was significantly warmer than the preindustrial climate is the mid-Pliocene warm period (MPWP, 3.3-3 Million years ago). Time-slab reconstructions of climate, ice-sheets and vegetation are available for the MPWP. With transient simulations using CLIMBER-2 we show, however, that orbital forcing has a significant impact on climate during the MPWP and a MPWP time-slice with orbital forcing similar to present-day would be more appropriate as a paleo-analog for future warming. We find that the vegetation feedback in synergy with the ice-sheet feedback amplifies the response of global temperature to orbital forcing.
The amount of CO_2 released to the atmosphere from land and ocean carbon pools as a response to a global temperature change provides a simple measure of the carbon cycle-climate feedback. We find that the carbon-cycle feedback is positive and shows a pronounced time-scale dependence. A maximum value is found at centennial time-scales and is comparable to the magnitude of the albedo feedback.
This work contributes to the assessment of the vegetation-climate and carbon cycle-climate feedbacks in a framework where they can be compared consistently with the fast climate feedbacks.