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Vegetation feedbacks in a Complex Earth System Model during the last interglacial

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An earth system model developed at the MPI consisting of complex 3-dimensional components of atmosphere (ECHAM3-AGCM), ocean (LSG2-OGCM), marine carbon cycle (HAMOCC), and dynamical terrestrial vegetation (LPJ) has been used to study feedbacks in the climate system during the transition from the last interglacial to the following glacial. The model has been forced with time varying insolation corresponding to the period from 129 to 113 kyBP. The model has a prognostic calculation of atmospheric CO_2, however, the simulated changes are rather small The experiments were run in two different coupling modes in order to assess the vegetation feedback: In a fully coupled mode and in a mode where the surface conditions for the AOGCM component were fixed according to present-day conditions. Two feedbacks were found that strongly amplify the response to insolation forcing when using interactive vegetation.

1) High latitude albedo - temperature feedback:

The model simulates a substantially warmer climate during the Eemian warm period of 2.8 K on the land points north of 60˚N. Compared to the simulation with prescribed present-day land surface parameters it can be seen that interactive vegetation strongly amplifies the simulated warming: In the simulation with prescribed vegetation the warming is 1.7 K. During the colder period at 115 kyBP the full model simulates a cooling of 1.8 K on high northern land points, the model without interactive vegetation simulates of cooling slightly below 1 K. The main difference between the two simulations is the strength of the simulated albedo changes. Whereas in the full simulation the mean annual land albedo north of 60˚N varies between 0.42 and 0.62, the effect is much smaller with prescribed vegetation. In the latter case the only mechanism to alter the land albedo is the presence/absence of snow and its temperature (freezing or melting). The seasonal cycle of high northern latitude land albedo reveals that the interactive vegetation affects the albedo throughout the entire year. With fixed vegetation the strongest differences between 125 and 115 kyBP appear in summer albedo, the simulated changes in winter and spring albedo are small: In any case it is cold enough for the existence of snow. But also the seasonal length with very low summer land-albedo (< 0.4) at 115 kyBP is 24 days shorter in the simulation using interactive vegetation which is considered to be a crucial factor for glacial inception. During the Eemian the interactive vegetation does not only lead to darker surfaces due to intensified vegetation cover in summer, but most of this vegetation is forest. Also during snow covered periods a forest covered area with snow has a darker albedo than grassland covered with snow. The darker surface leads to enhanced absorption of short wave radiation in spring and a faster snow melt, thus improving the condition for additional growth of forest. A similar feedback becomes effective during the cold period: Reduced forest cover amplifies the cooling.

2) Low latitude albedo precipitation feedback.

In both model versions, the intensified insolation during northern hemisphere summer leads to higher precipitation over most of the continents during the Eemian due to higher land-sea temperature contrasts. The maximum response is seen in the tropics and in the African-Asian monsoon belt. Lower precipitation is found over southern South America, South Africa, and Australia, which reflects a weaker monsoon in the Southern Hemisphere during austral summer when insolation was weakened causing lower land-sea temperature contrasts.

At 126 ka yearly mean precipitation anomalies exceed 80 mm/month (60mm/month) over NW-Africa and 120 mm/month (80 mm/month) over SE Asia in the fully coupled version (fixed vegetation). In the western part of the Sahara desert (10ºE – 20˚W; 10 - 30˚N) vegetation is established. This lowers the albedo and thus increases the response by a factor larger than two in the fully coupled model in the course of the Eemian. The associated evolution of vegetation coverage averaged over the Sahara region is more than twice as strong in the fully coupled model.

At 126 ka the maximum mean precipitation anomaly is found during August (when the monsoon is strongest) with $\sim$170 mm/month in the full model compared to $\sim$72 mm/month with fixed vegetation. These large anomalies are associated with increased cloud formation which together with increased surface evaporation leads to a cooling of the yearly mean temperature at 126 ka by more than 5 K in the fully coupled model.

Conclusion

The results demonstrate a substantial amplification of insolation forced climate feedbacks when using interactive dynamical vegetation compared to prescribed vegetation. The overall rationale behind these are albedo changes due to land surface dynamics that further affect the temperature and precipitation. With regard to the glacial inception the amplification of high latitude temperature feedback at 115 kyBP seems to be an essential precondition for the growth of continental ice sheets.

Supplementary material is continually provided under http://www.mpimet.mpg.de/en/depts/dep3/oph/deklim.html