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Interactions between climate and vegetation at high northern latitudes during the mid-Holocene

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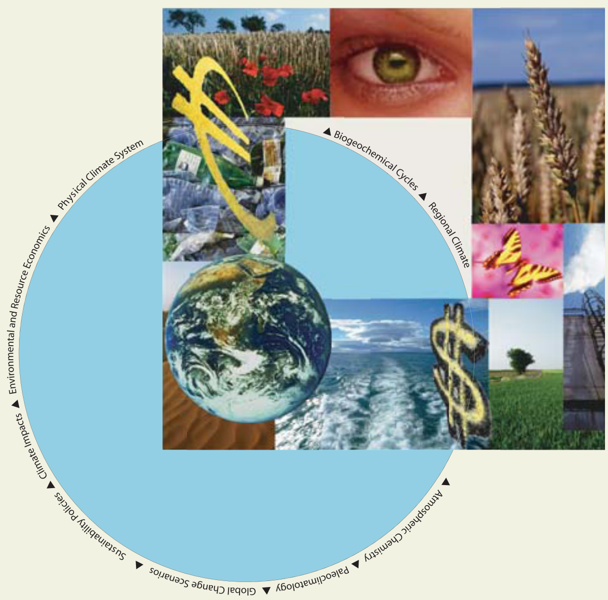

Abstract

The mid-Holocene climate, about 6000 years before present, is investigated with the comprehensive general circulation model ECHAM5/JSBACH-MPIOM at high northern latitudes. Applying a factor-separation technique, we isolate the contributions of the atmosphere, the atmosphere-vegetation feedback, the atmosphere-ocean feedback and their synergy to the mid-Holocene climate change signal.

The mid-Holocene climate signal shows a modification of the seasonal cycle at the high northern latitudes compared to pre-industrial climate. This is characterised by increased temperatures in summer, autumn and winter, and a cooler climate in spring. The summer warming is primarily caused by the direct response of the atmosphere to the change in insolation. The autumn temperature rise, however, results not only from the direct atmospheric signal but is also amplified by the atmosphere-ocean feedback. The winter warming is primarily induced by the atmosphere-ocean feedback, counteracting the cooling caused by the the direct atmospheric signal. In spring, the temperature decrease is a combined effect of the direct atmospheric signal and the atmosphere-ocean feedback. The atmosphere-vegetation feedback compensates this cooling only marginally. The synergy between the atmosphere-ocean and atmosphere-vegetation feedback results in slight warming for all seasons. In summary, the direct mid-Holocene climate response to the change in insolation is mainly modified by the atmosphere-ocean feedback. In contrast, the atmosphere-vegetation feedback influences the mid-Holocene climate signal only marginally.

We test the statistical robustness of the results. The atmosphere response and the atmosphere-vegetation feedback are statistically robust. By contrast, the factors derived from simulations with an interactive ocean are sensitive to long-term anomalies in sea-ice cover. Nevertheless, the statistical testing confirms that the most important modification of the direct climate response to the orbital forcing can be related to the atmosphere-ocean feedback.

A detailed analysis of the atmosphere-vegetation feedback shows that the expansion of forest during the mid-Holocene causes two opposing effects in spring. On the one hand, the increase in forest results in a reduction in surface albedo and, thus, enhances the absorption of solar radiation which leads to a near-surface air-temperature rise. On the other hand, the expansion of forest favours the increase in transpiration and, thus, an increase in cloud fraction, which, in turn, dampens the warming signal. Furthermore, it is investigated to what extent the strength of the atmosphere-vegetation feedback depends on the parametrisation of the albedo of snow. A parametrisation with a strong reduction in the albedo of snow by deciduous trees increases the temperature signal regionally. Simulations with the albedo of snow depending on the age of snow show a regional increase in temperature as well. However, the large-scale temperature signal of the atmosphere-vegetation feedback simulated with ECHAM5/JSBACH remains weak compared to previous studies.