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Warm and sensitive Paleocene-Eocene climate

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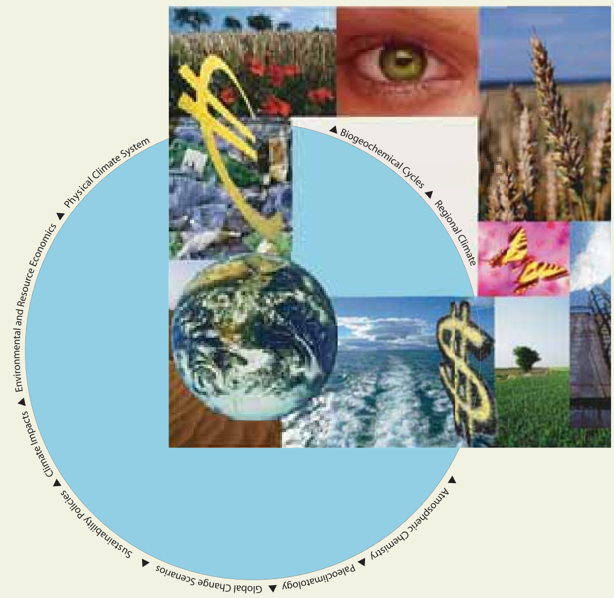

Abstract

We investigate the late Paleocene to early Eocene (PE) climate about 55 million years ago, and its sensitivity to a variation of atmospheric carbon dioxide concentrations (pCO_2) using the coupled atmosphere-ocean-sea ice general circulation model ECHAM5/MPI-OM.

Applying a moderate pCO_2 of 560 ppm yields a warm and ice-free climate with, compared to a pre-industrial reference, 5 to 8 K warmer low latitudes and up to 40 K warmer high latitudes. This high-latitude amplification is in line with proxy data, yet the Arctic surface temperatures may still be too low. Using a zero-dimensional energy balance model as a diagnostic tool reveals that about two thirds of the warming are due to a reduced atmospheric longwave emissivity, mostly from an increased atmospheric water vapour content. The remaining one third of the warming is due to a reduced planetary albedo. The planetary albedo reduction is caused by the lack of glaciers, the lack of sea ice, reduced snow cover, and a darker vegetation. We suggest that these local radiative effects, rather than increased meridional heat transports, were responsible for the low equator-to-pole temperature gradient during the PE.

Increasing pCO_2 from 560 to 840 ppm yields an additional surface warming of 3.8 K, further increasing pCO_2 to 1120 ppm yields a runaway climate. The warming during both pCO_2 increase experiments is caused by a decreased longwave emissivity of the clear sky atmosphere and a decreased shortwave cloud radiative effect, at a ratio of about 3:1. The large climate sensitivities have to be regarded with caution, as they may in part be caused by an artificial interaction with ozone.

Irrespective of the pCO_2, we find North Atlantic Deep Water (NADW) formation in the proto-Labrador Sea and a southward deep western boundary current in all stable simulations. The NADW becomes shallower for larger pCO_2. Southern Ocean deep water formation for a pCO_2 of 560 ppm is relatively weak, exhibits centennial oscillations, and drives a northward deep water flow in the eastern Atlantic. Decreasing pCO_2 from 560 to 280 ppm leads to the onset of strong South Pacific sinking. Increasing pCO_2 from 560 to 840 ppm yields reduced Southern Ocean sinking. We do not find sinking in the North Pacific in any of our runs.

Summing up, we present the first coupled PE climate model solution with moderate pCO_2 that shows relatively warm, sea-ice-free high latitudes, and still reasonably matches lower-latitude sea surface temperature reconstructions. Our runs do not support the notion that an ocean circulation switch triggered the Paleocene/Eocene Thermal Maximum (PETM). However, our results indicate that the PE climate was very sensitive to a variation of pCO_2, which implies that a relatively small input of carbon — possibly from methane hydrates — could have caused the warming during the PETM.