Evolution of the seasonal temperature cycle in a transient Holocene simulation: orbital forcing and sea ice

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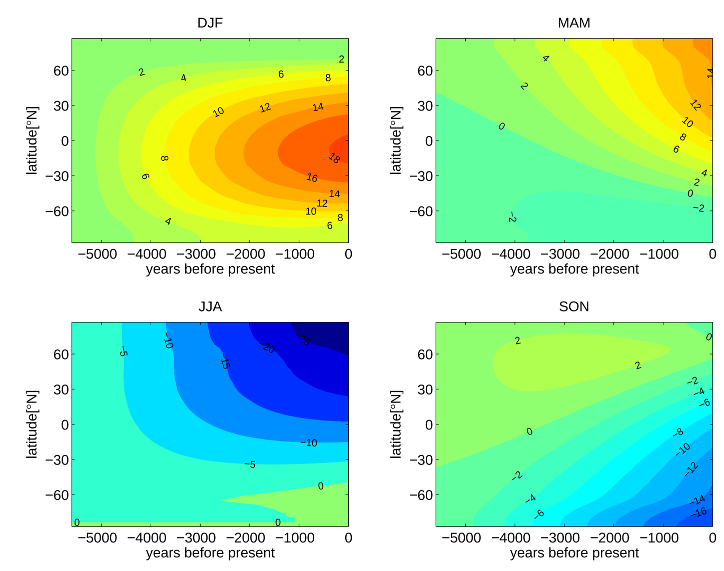
1. Introduction

- Changes in the Earth's orbit induce changes in the seasonal and meridional distribution of insolation.
- During the mid-Holocene, enhanced obliquity and summer solstice being closer to perihelion than today lead to an increase in the seasonal insolation cycle in the Northern Hemisphere.
- So far, it has been assumed that the changes in insolation directly influence the temperature response.
- We quantify the influence of orbitally induced changes on the seasonal temperature cycle in a transient simulation of the last 6.000 years - from the mid-Holocene to today - with a comprehensive general circulation model (ECHAM5/JSBACH/MPI-OM).
- What effects, beside the direct insolation response, affect the seasonal temperature cycle in the Holocene?

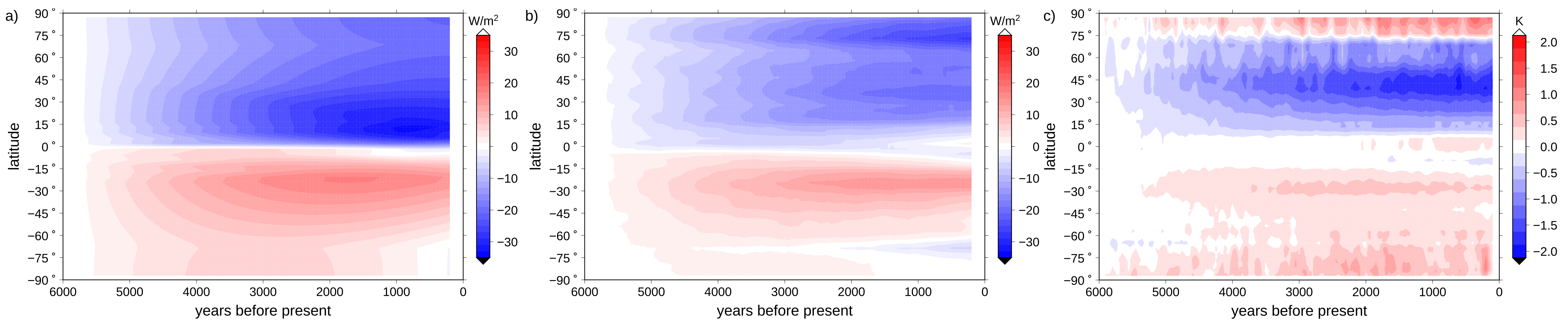
2. Experimental Set-Up

- fully coupled atmosphere-ocean model (ECHAM5/JSBACH/MPI-OM)
- resolution: atmosphere T31 (≙ 3.75°)
  ocean GR30 (≈ 3°)
- initialized from a 3,500 year timeslice simulation under mid-Holocene orbital conditions
- orbital forcing following VSOP87 (Bretagnon and Francou 1988) implemented in ECHAM5 (right figure: seasonal changes compared to mid-Holocene conditions)
- no acceleration technique applied



3. Results

3.1 Meridional temperature response to insolation changes

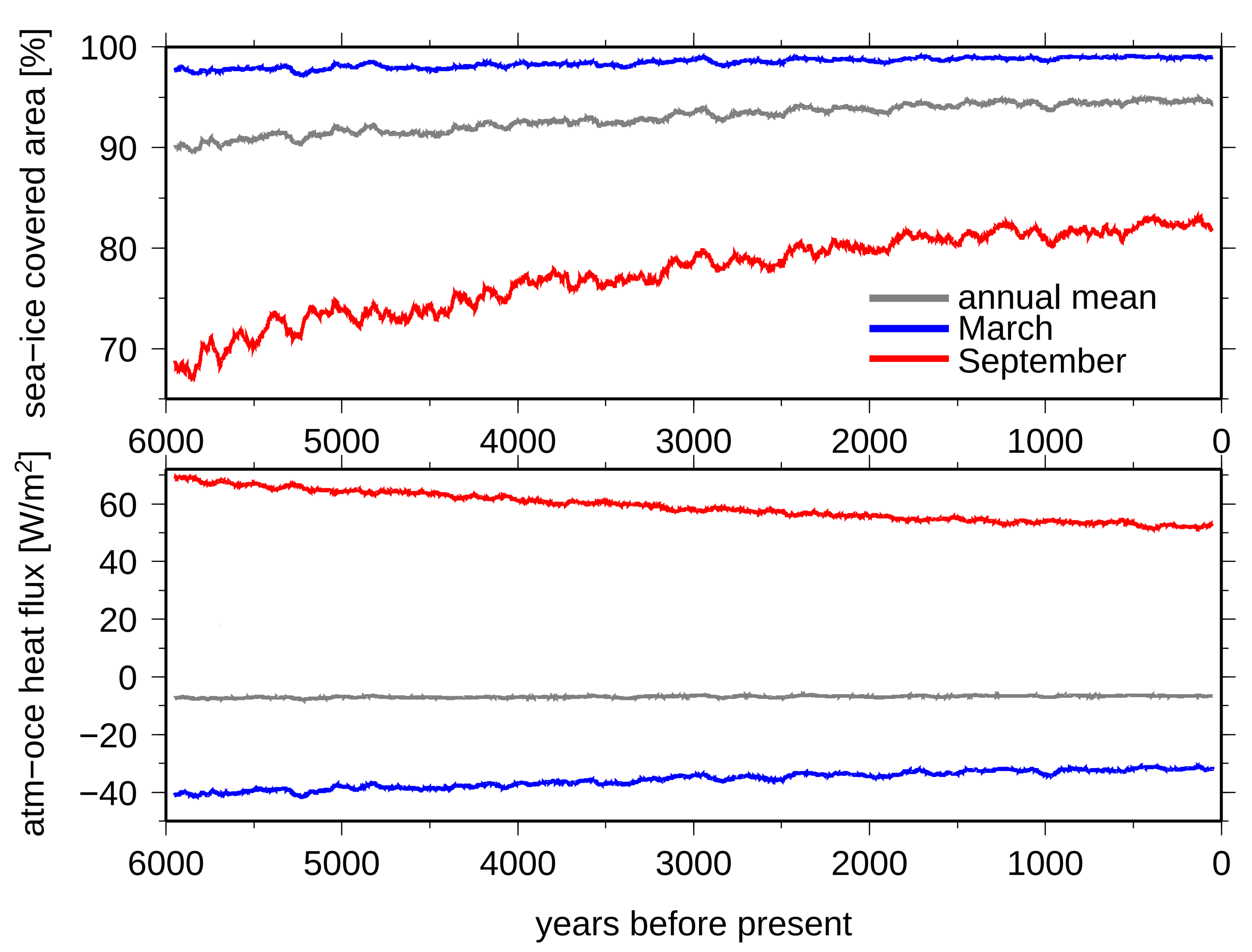


a) Latitudinal differences in the seasonal insolation cycle with respect to mid-Holocene conditions show a decrease in the Northern Hemisphere and a decrease in the Southern Hemisphere with maximum changes in the low latitudes.

b) Taking into account planetary albedo and, thus, looking at net incoming insolation, the low-latitude maxima shift to mid-latitudes and sea ice decreases the seasonal insolation cycle in both hemisphere's high latitudes.

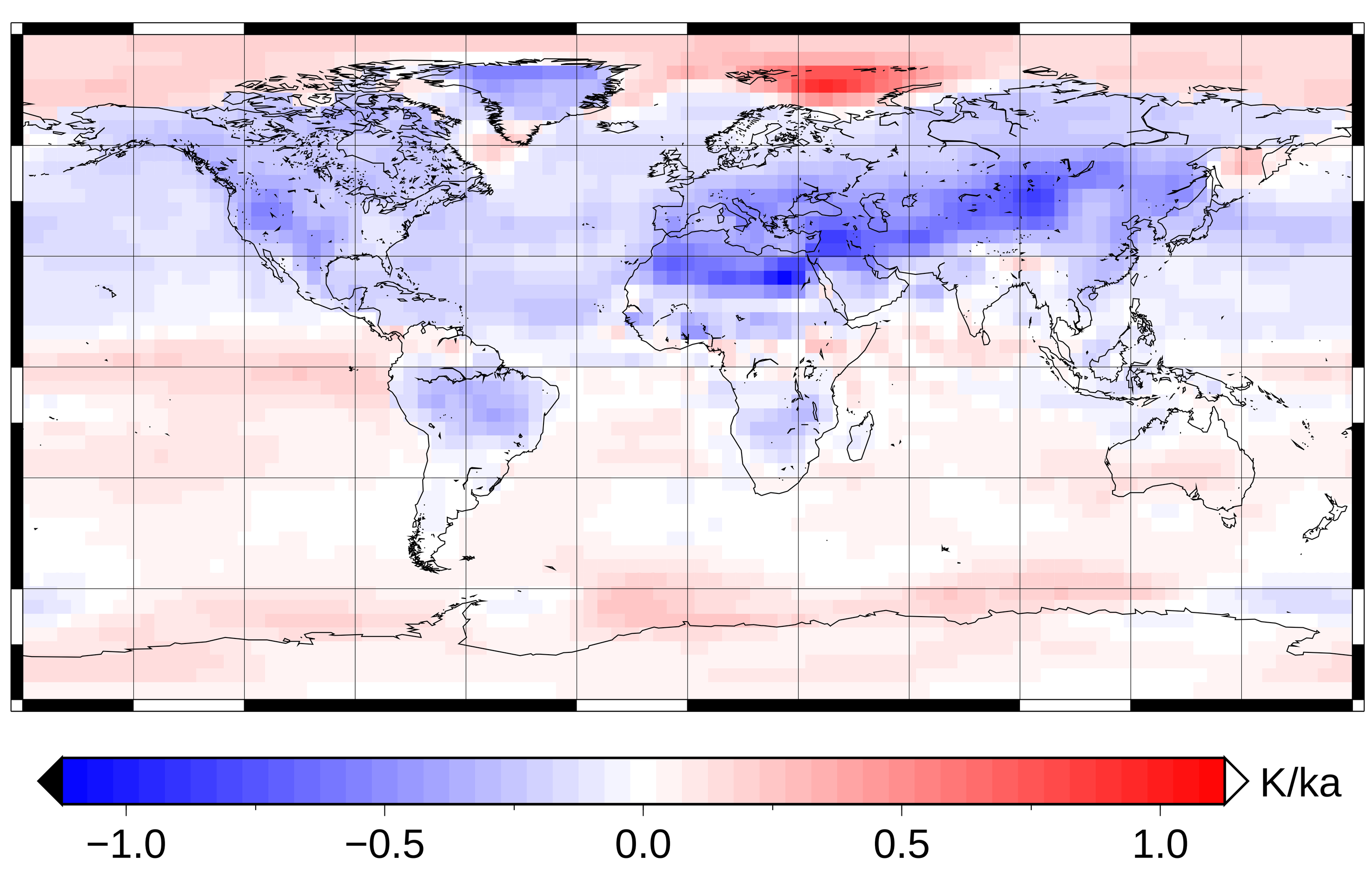
c) The temperature seasonal cycle amplitude, however, diverges from the insolation cycle and exhibits an increase in the high northern latitudes. In the Southern Hemisphere's high latitudes the increase is enhanced.

3.2 Evolution of Arctic sea ice and atm-oce heat fluxes



Despite the annual mean increase in sea-ice cover, the seasonal cycle amplitude in sea-ice cover decreases due to an increase in summer sea-ice cover (upper panel). Continental boundaries circumvent the further expansion of winter sea ice. This has implications for the atmosphere-ocean heat flux (lower panel), with less ocean heat uptake during the summer and less ocean heat release in the winter. Sea ice acts as an insulator, allowing for strongly decreasing temperatures in winter.

3.3 Spatial trends in the seasonal temperature cycle



Linear trend in seasonal temperature amplitude over the simulation period (in K/ka - Kelvin per 1,000 years.). The increase in the high northern latitudes is confined to the sea-ice influenced Arctic Ocean. The decrease over the Northern Hemisphere continents is decreased in the regions adjacent to the Arctic Ocean. The strong positive signal over the Barents Shelf influences the seasonal cycle response over northern Europe and parts of Asia, leading to a diminished decrease in seasonal temperature cycle amplitude.

4. Discussion

- Changes in seasonal temperature cycle amplitude follow those in insolation amplitude in general with the exception of the high northern latitudes where, despite decreasing amplitude of the seasonal insolation cycle, the amplitude of the seasonal temperature cycle increases.
- The difference between seasonal temperature cycle amplitude and insolation amplitude can be attributed to planetary albedo effects in low and mid latitudes, but cannot explain the increase in high northern latitudes.
- The increase in sea-ice cover in the Arctic Ocean and its insulating effect prevent the ocean from acting as a heat reservoir, gaining heat in summer and releasing it to the atmosphere in winter.

5. Conclusion

- The seasonal temperature cycle amplitude in the Holocene is determined by seasonal insolation distribution in the low and mid latitudes and by sea ice in the high latitudes.
- In the Northern Hemisphere, the sea-ice effect outweighs the insolation effect, in the Southern Hemisphere, the sea-ice effect amplifies the insolation effect.
- Despite the decrease in the seasonal insolation cycle amplitude, the amplitude of the seasonal temperature cycle increases in the Arctic Ocean and diminishes the seasonal temperature cycle amplitude's increase on the adjacent continents.
- Annual mean temperature changes in the high northern latitudes are dominated by a decrease in winter temperatures, whereas summer temperatures decrease to a lesser extent.

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