Effects of melting ice sheets and orbital forcing on the early Holocene warming in extratropical Northern Hemisphere

Y. Zhang [1 & 2 *], H. Renssen [2] and H. Seppä [1]

[1] *Department of Geosciences and Geography, University of Helsinki, P.O.BOX 64, FI00014 Helsinki, Finland (*correspondence: yurui.zhang@helsinki.fi)*

[2] *Faculty of Earth and life Sciences, VU University Amsterdam, De Boelelaan 1085, 1081 HV Amsterdam, Netherlands*

The early Holocene is a critical period for climate change, as it marked the final transition from the last deglaciation to the relatively warm and stable Holocene. It is characterized by a warming trend that has been registered in numerous proxy records and was accompanied by major adjustments in different climate components. The climate response to the forcings together with the internal feedbacks before 9 ka remains not fully comprehended. In this study, we therefore disentangle how these forcings contributed to climate change during the earliest part of Holocene (11.5–7 ka) by employing the LOVECLIM climate model for both equilibrium and transient experiments.

The results of our equilibrium experiments for 11.5 ka reveal that the annual mean temperature at 11.5 ka was lower than the present in the Northern extratropics, except in Alaska. The magnitude of this cool anomaly varies regionally as a response to varying climate forcings and diverse mechanisms. In eastern N America and NW Europe the temperatures throughout the whole year were 2–5 °C lower than in the preindustrial control as here the climate was strongly influenced by the cooling effects of the ice sheets. This cooling of the ice-sheet surface was caused both by the enhanced surface albedo and by the orography of the ice sheets. For Siberia, a small deviation in summer temperature and 0.5–1.5 °C cooler annual climate compared to the present were caused by the counteraction of the high albedo associated with the tundra vegetation which was more southward extended at 11.5 ka than in the preindustrial period and the orbitally-induced radiation anomalies. In the eastern Arctic Ocean, the annual mean temperature was 0.5–2 °C lower than at 0 ka, because the cooling caused by a reduced northward heat transport overwhelmed the orbitally-induced warming. In contrast, in Alaska, temperatures in all seasons were 0.5–3 °C higher than the control run primarily due to the orbitally-induced positive insolation anomaly and also to the enhanced southerly winds which advected warm air from the South as a response to the high air pressure over the Laurentide Ice Sheet.

Our transient experiments indicate that the Holocene temperature evolution and the early Holocene warming also vary between different regions. In Alaska, the climate is constantly cooling over the whole Holocene. In contrast, the overall warming during the early Holocene is faster in N Canada than in other areas (up to 1.88 °C ka^{-2} in summer) as a consequence of the progressive decay of the LIS. In NW Europe, the Arctic and Siberia, the overall warming rates are intermediate with about 0.3–0.7 °C ka^{-2} in most of seasons. Overall, our results demonstrate the spatial variability of the climate during the early Holocene, both in terms of the temperature distribution and warming rates, as the response to varying dominant forcings and diverse mechanisms.