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Sensitivity of Pliocene Arctic climate to orbital forcing, atmospheric CO_2 and sea ice albedo parameterisation

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General circulation model (GCM) simulations of the mid-Pliocene Warm Period (mPWP, 3.264 to 3.025 Myr ago) do not reproduce the magnitude of Northern Hemisphere high latitude surface air and sea surface temperature (SAT and SST) warming that proxy data indicates. There is also large uncertainty regarding the state of sea ice cover in the mPWP. Evidence for both perennial and seasonal mPWP Arctic sea ice is found in analyses of marine sediments, whilst in a multi-model ensemble of mPWP climate simulations, half of the ensemble simulated ice-free summer Arctic conditions. Given the strong influence that sea ice exerts on high latitude temperatures, a better understanding of the nature of mPWP Arctic sea ice would be highly beneficial in understanding proxy derived estimates of high latitude surface temperature change, and the ability of climate models to reproduce this.

In GCM simulations, the mPWP is typically represented with fixed orbital forcing, usually identical to modern, and atmospheric CO_2 concentrations of $\sim$ 400 ppm. However, orbital forcing varied over the $\sim$ 240,000 years of the mPWP, and it is likely that atmospheric CO_2 varied as well. A previous study has suggested that the parameterisation of sea ice albedo in the HadCM3 GCM may not reflect the sea ice albedo for a warmer climate, where seasonal sea ice constitutes a greater proportion of the Arctic sea ice cover. These three factors, in isolation and combined, can greatly influence the simulation of Arctic sea ice cover and the degree of high latitude surface temperature warming.

This paper explores the impact of various combinations of potential mPWP orbital forcing, atmospheric CO_2 concentrations and minimum sea ice albedo on sea ice extent and high latitude warming. The focus is on the Northern Hemisphere, due to availability of proxy data, and the large data-model discrepancies in this region. Changes in orbital forcings are demonstrated to be sufficient to alter the Arctic sea ice simulated by HadCM3 from perennial to seasonal, although only when atmospheric CO_2 concentrations exceed 300 ppm. Reduction of the minimum sea ice albedo from 0.5 to 0.2 is also sufficient to simulate seasonal sea ice, with any of the combinations of atmospheric CO_2 and orbital forcing. Compared to a mPWP control simulation, monthly mean increases north of 60°N of up to 4.2°C (SST) and 9.8°C (SAT) are simulated. However, data-model comparisons show the model temperatures still fail to match the proxy data temperatures. It is suggested that further high latitude warming may be achieved through adjustments to cloud parameterisation, although the gap between model and data temperature in simulations, even with significantly reduced sea ice cover compared to the control, suggests that agreement may still be difficult to achieve.