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Sensitivity of Mid-Pliocene climate to changes in boundary condition: lessons from COSMOS within PlioMIP

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In this study, we present results obtained from modelling the mid-Pliocene warm period using the Community Earth System Models (COSMOS, version: COSMOS-landveg r2413, 2009) with the two different sets of boundary conditions prescribed for the two phases of the Pliocene Model Intercomparison Project (PlioMIP). Boundary conditions, model forcing, and modelling methodology of the two phases of PlioMIP, tagged PlioMIP1 and PlioMIP2, differ considerably in palaeogeography, in particular with regards to the state of ocean gateways, ice-masks, vegetation and topography. Further differences between model setups as suggested for PlioMIP1 and PlioMIP2 consider updates to the concentration of atmospheric carbon dioxide (CO_2), that is specified as 405 and 400 parts per million by volume (ppmv) for PlioMIP1 and PlioMIP2, respectively, as well as minor differences in the concentrations of methane (CH4) and nitrous oxide (N2O) due to changes in the protocol of the Paleoclimate Model Intercomparison Project (PMIP) from phase 3 to phase 4. With this manuscript, we bridge the gap between our contributions to PlioMIP1 (Stepanek and Lohmann, 2012) and PlioMIP2 (Stepanek et al., 2019). We highlight some of the effects that differences in the chosen Mid-Pliocene model setup (PlioMIP2 vs. PlioMIP1) have on the climate state as derived with the COSMOS, as this information will be valuable in the framework of the model-model and model-data-comparison within PlioMIP2. We evaluate the model sensitivity to improved mid-Pliocene boundary conditions using PlioMIP's core mid-Pliocene experiments for PlioMIP1 and PlioMIP2, and present further simulations where we test model sensitivity to variations in palaeogeography, orbit and concentration of CO_2. Firstly, we highlight major changes in boundary conditions from PlioMIP1 to PlioMIP2 and also the limitations recorded from the initial effort. The results derived from of our simulations show that COSMOS simulates a mid-Pliocene climate state that is 0.08 K colder in PlioMIP2, if compared to PlioMIP1. On one hand, high-latitude warming, which is supported by proxy evidence of the mid-Pliocene, is underestimated in simulations of both PlioMIP1 and PlioMIP2. On the other hand, spatial variations in surface air temperature (SAT), sea surface temperature (SST) as well as the distribution of sea ice suggest improvement of simulated SAT and SST in PlioMIP2 if employing the updated palaeogeography. The PlioMIP2 Mid-Pliocene simulation produces warmer SSTs in the Arctic and North Atlantic Ocean than derived from the respective PlioMIP1 climate state. The difference in prescribed CO_2 accounts for 1.1 K of warming in the Arctic, leading to an ice-free summer in the PlioMIP1 simulation, and a quasi-ice-free summer in PlioMIP2. Furthermore, employing different orbital forcings in simulating the Mid-Pliocene lead to pronounced annual and seasonal variations, which is not accounted for by marine and terrestrial reconstruction of the time-slice.