Simulation of the mid-Pliocene Warm Period using HadGEM3-GC31-LL: Pliocene climate relative to the pre-industrial era, previous model versions, other climate models and proxy data

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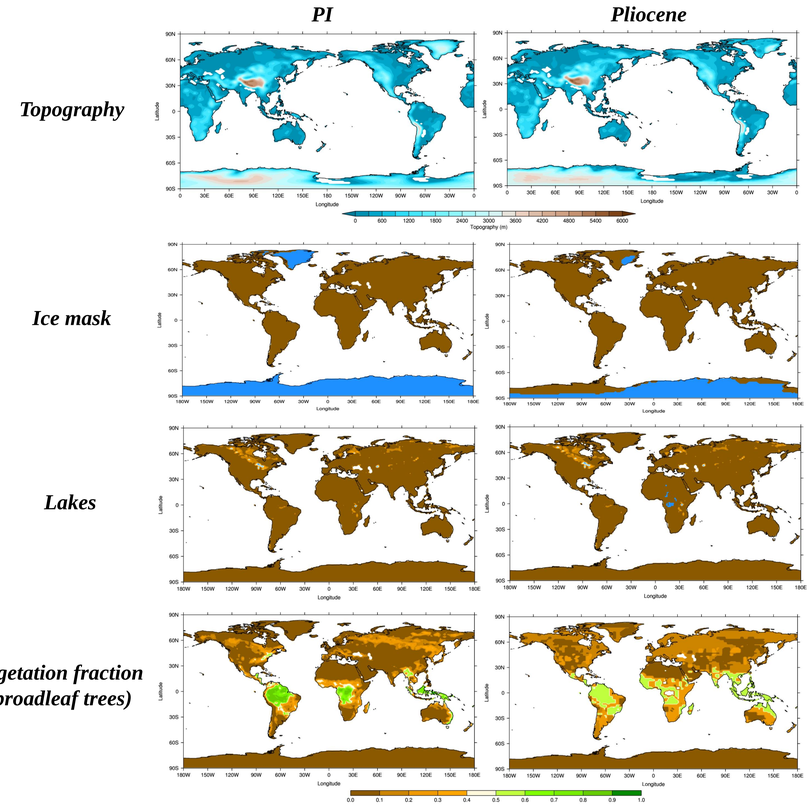
1) Introduction

- To better understand the processes contributing to future climate change, palaeoclimate Global Climate Model (GCM) simulations are an important tool because they allow testing of the models' ability to simulate very different climates than that of today
- As part of Phase 6 of the Coupled Model Intercomparison Project / Phase 4 of the Palaeoclimate Modelling Intercomparison Project (CMIP6/PMIP4), the latest version of the UK's physical climate model, HadGEM3, was used to simulate the mid-Holocene (~6 ka) and Last Interglacial (~127 ka) simulations and the results were compared to the preindustrial era (PI), previous versions of the same model and proxy data (see companion poster)
- Here, we use the same model to go further back in time, presenting the results from a simulation of the mid-Pliocene Warm Period (~3.3 to 3 Ma, hereafter the "Pliocene"). This period is of particular interest concerning projections of future climate change under various scenarios of CO_2 emissions, because it is the most recent time in Earth's history when CO_2 levels were roughly equivalent to today. In response, albeit due to slower mechanisms than today's anthropogenic fossil fuel driven-change, during the Pliocene global mean temperatures were 2-3°C higher than today, more so at the poles
- Here, we present the results from the HadGEM3-GC31-LL Pliocene simulation, comparing the results to the PI, to earlier versions of the same model and proxy data, and to all other Pliocene simulations conducted under PlioMIP2
- This is the first time this version of the UK model has been used to conduct palaeoclimate simulations, and contribute to CMIP6/PMIP4, this far back in time

2) Model, experiment designs and proxy data

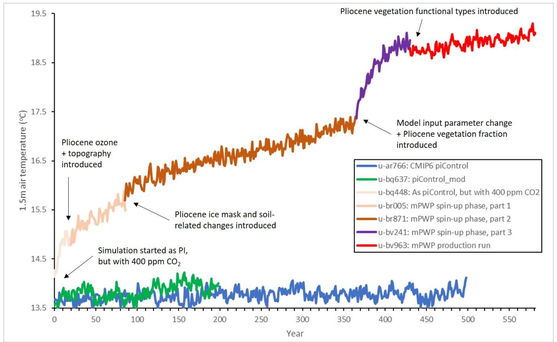
- **Primary model** - The Pliocene simulation conducted here, and the PI simulation, were all run using the same fully-coupled GCM: the Global Coupled 3 configuration of the UK's physical climate model, HadGEM3-GC31-LL (for brevity, HadGEM3)
- **Other models** - In addition to comparing the HadGEM3 Pliocene simulation with the model's corresponding PI, it was also compared to Pliocene simulations from previous versions of the same model, namely HadGEM2 and HadCM3, and with all other available models from PlioMIP2
- **Main experiment design** - The Pliocene simulation followed the experimental design given by Haywood *et al*. (2016). The main differences from the PI were to the atmospheric trace greenhouse gas concentrations (set to 400 ppm in the Pliocene), topography, ice mask (including snow and soil properties), lakes and vegetation. See Section 3. All other boundary conditions, including the land-sea mask, solar activity, volcanic activity etc, are identical to the PI simulation, as are the ocean boundary conditions such as ocean temperature and salinity
- **Modified PI** - Due to a change of model input parameters in the Pliocene simulation, a new PI was also run with these changes, to be consistent
- **Proxy data** - The global-scale PlioVAR KM5c Database is used here, in which sea surface temperatures (SST) are synthesised through a 20 kyr timeslice of KM5c (3.195-3.215 Ma) by McClymont *et al*. (2020)

3) Pliocene setup



Examples of modifications used in Pliocene simulation

4.1) Results – Entire simulation



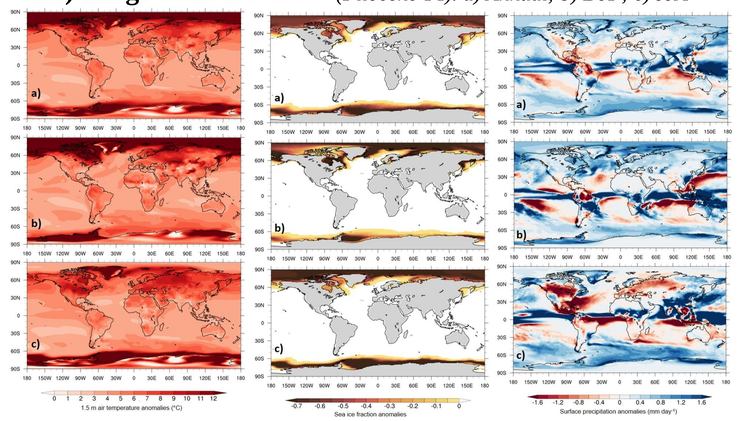
Global annual mean 1.5 m air temperature from entire Pliocene simulation, compared to PI and modified PI. Colours represent different stages of the simulation, gradually changing from PI conditions to Pliocene. Red line shows final stage of Pliocene simulation, of which last 50 years were used to create climatologies (see Section 4.2)

Take-home points: The Pliocene simulation was run in stages, beginning as a straight PI run and then gradually introducing Pliocene elements (e.g. CO_2, ozone and topography, then ice mask, then vegetation etc). There is a clear increase in temperature (of ~2°C) when Pliocene vegetation changes are introduced. Overall change in temperature between end of Pliocene simulation and PI: 5.1°C.

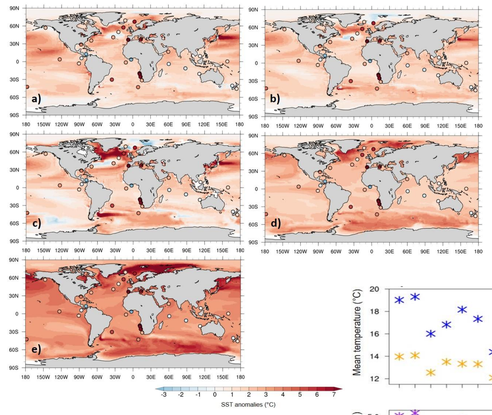
4.2) Results

4.2.1) Large-scale features

1.5 m air temperature (left), sea ice (middle) and precipitation (right) climatology differences (Pliocene-PI). a) Annual; b) DJF; c) JJA

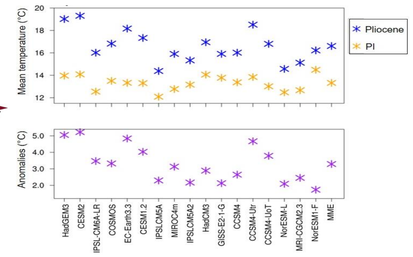


4.2.2) Model-data comparison with previous model generations



SST climatology differences (Pliocene-PI) from different generations of the UK's physical climate model. a) HadCM3 v1; b) HadCM3 v2; c) HadCM3 v3; d) HadGEM2; e) HadGEM3. Background gridded data shows model simulations, filled circles show SST proxy data

4.2.3) Model-model comparison with PlioMIP2 models



Global annual mean 1.5 m air temperature differences (Pliocene-PI) from Pliocene simulations from HadGEM3 and all other models in PlioMIP2

Take-home points: Firstly (Section 4.2.1), a comparison with the PI suggests that the Pliocene simulation is consistent with existing work, showing warmer and wetter conditions, and with the greatest warming occurring over high latitude and polar regions. Secondly (Section 4.2.2), a comparison with previous generation models and with proxy data suggests a clear increase in global sea surface temperatures as the model has undergone development, but that HadGEM3 may now be too warm. Thirdly (Section 4.2.3), when compared to other models, HadGEM3 is one of the warmest (and wettest, not shown) models in all of PlioMIP2.

- Haywood, A, M., Dowsett, H. J., Dolan, A., M. *et al*. (2016), https://doi.org/10.5194/cp-12-663-2016
- McClymont, E. L., Ford, H. L,. Ho, S. L. *et al*. (2020), https://doi.org/10.5194/cp-16-1599-2020

Williams *et al*. (2021). *Climate of the Past*. In review.

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