Geosci. Model Dev. Discuss., 4, 445–456, 2011
www.geosci-model-dev-discuss.net/4/445/2011/
doi:10.5194/gmdd-4-445-2011

Geoscientific
Model Development
Discussions

Pliocene Model Intercomparison Project (PlioMIP): experimental design and boundary conditions (Experiment 2)

A. M. Haywood[1], H. J. Dowsett[2], M. M. Robinson[2], D. K. Stoll[2], A. M. Dolan[1], D. J. Lunt[3], B. Otto-Bliesner[4], and M. A. Chandler[5, 6]

[1]School of Earth and Environment, University of Leeds, Woodhouse Lane, Leeds, LS2 9JT, UK
[2]Eastern Geology and Paleoclimate Science Center, US Geological Survey, MS926A, 12201 Sunrise Valley Drive, Reston, VA 20192, USA
[3]School of Geographical Sciences, University of Bristol, University Road, Bristol, BS8 1SS, UK
[4]CCR, CGD/NCAR, P.O. Box 3000, Boulder, CO 80307-3000, USA
[5]Center for Climate Systems Research, Columbia University, 2880 Broadway, New York, NY, 10025, USA
[6]NASA Goddard Institute for Space Studies, New York, NY, USA

Received: 18 February 2011 – Accepted: 23 February 2011 – Published: 2 March 2011

Correspondence to: A. M. Haywood (earamh@leeds.ac.uk)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

The Palaeoclimate Modelling Intercomparison Project has expanded to include a model intercomparison for the mid-Pliocene warm period (~3.3 to 3.0 million yr ago). This project is referred to as PlioMIP (Pliocene Model Intercomparison Project). Two experiments have been agreed and together compose phase 1 of PlioMIP. The first (Experiment 1) is being performed with atmosphere-only climate models. The second (Experiment 2) is utilising fully coupled ocean-atmosphere climate models. Following on from the publication of the experimental design and boundary conditions for Experiment 1 in Geoscientific Model Development, this short paper provides the necessary description of differences and/or additions to the experimental design for Experiment 2.

1 Introduction

For the initial phase of the Pliocene Model Intercomparison Project (hereafter referred to as PlioMIP), two experiments were agreed. The first is an experiment using atmosphere-only climate models (hereafter referred to as Experiment 1), the details of which can be found in Haywood et al. (2010), whilst the second experiment (hereafter referred to as Experiment 2) is utilising coupled ocean-atmosphere climate models. Both experiments use versions of the US Geological Survey's PRISM Group boundary condition data sets. This Special Issue of *Geoscientific Model Development* represents the first set of co-ordinated publications from the PlioMIP project. It (a) describes the chosen experimental design for Experiments 1 and 2, (b) includes a detailed description of the boundary conditions used in both experiments, and (c) presents contributions from each participating model group, describing how the boundary conditions were implemented into the different climate models and the basic results from the experiments themselves. This detailed record for the rationale and specifics of the experimental design, construction of the boundary condition data sets, and critically, how these were implemented into each climate model, will provide a valuable reference when the intercomparison phase of PlioMIP is reached. This will help the PlioMIP/PMIP community to understand more easily the differences which will inevitably be observed between mid-Pliocene warm period (mPWP) simulations. The purpose of this paper is to briefly describe the experimental design and boundary conditions for PlioMIP Experiment 2 – focussing only on the aspects that differ from Experiment 1. Participating groups should refer to Haywood et al. (2010), for full details of Experiment 1 and for details relevant to Experiment 2 that are not repeated here.

2 Experimental design – Experiment 2

2.1 Integration, atmospheric gases/aerosols, solar constant/orbital configuration

The experimental design for Experiment 2 is summarised in Table 1. The experiment integration length was set to 500 yr in accordance with CMIP5 guidelines for coupled model experiments (see: http://cmip-pcmdi.llnl.gov/cmip5/docs/Taylor_CMIP5_design.pdf). As in PlioMIP Experiment 1, the concentration of CO_2 in the atmosphere was set to 405 ppmv which is a little more than the average range (~360 to 380 ppmv) of mPWP CO_2 indicated by available proxy data (Kürschner et al., 1996; Raymo et al., 1996). The CO_2 value was chosen to also account for possible additional contributions to greenhouse warmth from non-CO_2 greenhouse gases such as methane, for which we have no proxy record in the Pliocene, a possibility which is consistent with the coupled nature of variation in CO_2 and methane concentrations observed in Quaternary ice core records (e.g. Loulergue et al., 2008; Lüthi et al., 2008). In the absence of any adequate proxy data, all other trace gases and aerosols were specified to be consistent with the individual group's pre-industrial control experiments, as was the solar constant.

The orbital configuration was specified as the same as each participating group's pre-industrial control run. The PRISM3D data set of mid-Pliocene boundary conditions represents an average of warm intervals during the time slab (~3.3 to 3.0 million yr) rather than a discrete time slice, making it challenging to prescribe an orbital configuration which is representative of the entire ~300 000 yr interval. Furthermore, it is difficult to provide an average insolation forcing at the top of the atmosphere in some climate models, with some models requiring specific values for eccentricity, obliquity and precession. Therefore, PlioMIP decided to specify a modern orbital configuration, even though available astronomical solutions (e.g. Laskar et al., 2004) indicate that this may not provide the most representative mean orbital forcing for the mPWP (see Haywood et al., 2010).

2.2 Implementation of ocean temperatures and topography as an anomaly

To ensure that the climate anomalies (mid-Pliocene minus pre-industrial) from all PlioMIP climate models are directly comparable, i.e. that they reflect differences in the models themselves rather than the differences of modern boundary conditions, it was decided to implement both the Pliocene topography and initial sea surface temperatures (SST) (from Experiment 1) and deep ocean temperatures (from Experiment 2) as an anomaly to the standard modern ocean temperature and topographic data set used by each modelling group's individual model. For Experiment 2 to create the initial Pliocene ocean temperature and topography, the difference between the PRISM_Pliocene and PRISM_Modern ocean temperatures and topography will be calculated and added to the modern ocean temperature and topographic data sets each participating modelling group employs.

Such that:

$$\text{Topo\_Plio}=(\text{Topo\_Plio\_PRISM3D}-\text{Topo\_Modern\_PRISM3D})+\text{Topo\_Modern\_Local} \quad (1)$$

and

$$\text{OceanT\_Plio}=(\text{OceanTemp\_Plio\_PRISM3D}-\text{OceanT\_Modern\_PRISM3D})+\text{OceanT\_Modern\_Local} \quad (2)$$

However, when using such a method, a potential mismatch between mid-Pliocene and modern topography land-sea masks is possible. This will be overcome by using absolute Pliocene topography and ocean temperatures in regions where no modern data are given (such as for the Pliocene topography in the Hudson Bay region). Modern SST is projected on the same Pliocene grids (*preferred* and *alternate*) to make anomalies easier to generate. There may be mismatches (for example in the West Antarctic region) between the Pliocene deep ocean temperature data, where it is provided, and the Pliocene land/sea mask. Where this is the case, *Global_dot_v2.0* deep ocean temperatures should be extrapolated horizontally into regions with no data coverage, therefore maintaining the *Global_dot_v2.0* vertical temperature profile. Groups unable to alter the initial ocean temperature state should begin the simulation with a modern control state and document the spin-up of the simulation. Salinity should be derived from Levitus or an existing modern (control) simulation. The starting atmospheric conditions for Experiment 2 should be derived from the end of Experiment 1 if possible.

2.3 Adoption/availability of a "preferred" and "alternate" experimental design

Two boundary condition data packages are available – "preferred" and "alternate". Both data packages are provided on the PlioMIP website (http://geology.er.usgs.gov/eespteam/prism/prism_pliomip_data.html) and are provided as supplementary information to this paper. The preferred data package requires the ability to change the model's land/sea mask to a mid-Pliocene configuration. The alternate data package, with a modern land/sea configuration, is provided in order to maximise the potential number of participating groups in PlioMIP, since it is difficult in some climate models to successfully alter the land/sea mask. Groups that are not able to change their land/sea mask were asked to use their own modern land/sea mask. However, a PRISM3D/PlioMIP modern land/sea mask is provided in the alternate package to help guide the implementation of mid-Pliocene topography and vegetation etc. into different climate models.

Those groups who are able to adopt the preferred experimental design will have to adjust the bathymetry of the deglaciated West Antarctic region. To avoid numerical instabilities groups will specify a bathymetry with an average depth of 500 m, flat, and the grade this bathymetry into the modern bathymetry. For those models which are very sensitive to bathymetric alteration, groups are free to do what is necessary to enable a simulation to be successfully completed.

3 Description of boundary conditions (PRISM3D)

A full description of the mPWP land-sea mask (including the nature of ocean gateways) and topography (outside of ice sheet regions), ice sheet height and extent, SST, sea-ice extent, vegetation type and distribution, soils, lakes and river routing is provided in Haywood et al. (2010; this volume). Here it is only necessary to describe the construction and nature of the three-dimensional data set for ocean temperatures that groups have the option of using to initialise their ocean models for PlioMIP Experiment 2.

3.1 The PRISM3D data set of ocean temperatures

The PRISM 3-D ocean reconstruction is presented at a 4° latitude by 5° longitude resolution with 33 depth layers, based upon 27 localities, unevenly distributed among the ocean basins. While not optimal for generating a global reconstruction, this represents possibly the largest number of temperature estimates for any deep-water reconstruction from any time interval. Specific steps in the reconstruction methodology are listed in Dowsett et al. (2009) Supplement (http://www.clim-past.net/5/769/2009/cp-5-769-2009-supplement.pdf). Because the PRISM 3-D reconstruction is designed for coupled ocean-atmosphere general circulation models, it represents a reconstruction of a prescribed day, arbitrarily chosen to be 1 December. The PRISM3 November and December monthly SST reconstructions were averaged to approximate the SST for mid-Pliocene 1 December. A surface-temperature anomaly was created by subtracting the modern 1 December SST field (Reynolds and Smith, 1995) from the Pliocene 1 December data. The surface temperature anomaly was then added to the 0m layer of Levitus and Boyer (1994) (converted to a $4^\circ \times 5^\circ$ resolution) to create the PRISM

3-D 0 m reconstruction. Since no data points fall between 0 m and 1100 m in the deep ocean temperature data set, PRISM chose to use a mathematical function that decreases the weight of the surface anomaly with depth down to 1400 m (see Dowsett et al., 2009). Between 900 m and 1400 m that anomaly was further modified based upon data from Southern Ocean sites to accomplish an adjustment or vertical expansion of palaeo Antarctic Intermediate Water (AAIW).

In the Atlantic sector of the Southern Ocean, data suggest warmer palaeo North Atlantic Deep Water (NADW) expansion in the region relative to modern day. Warm anomalies for the mid-Pliocene at all sites are in keeping with the hypothesized warmer and stronger flux of *palaeo* NADW and diminished (colder) palaeo Antarctic Bottom Water (AABW) production relative to today. In the western Pacific, Sites that monitor Pacific Deep Water (PDW) today show small positive anomalies for the mid-Pliocene. PRISM interprets these data to indicate the overall warmer conditions of the water masses that mixed to form *palaeo* PDW. In the eastern Pacific, temperature data can be explained by a vertical displacement of AAIW concomitant with overall warming of PDW.

A complete discussion of the rationale and methodology used for the PRISM Deep Ocean Temperature reconstruction can be found in Dowsett et al. (2009).

4 Variables, output format, data processing/storage, planned analyses

PlioMIP Phase 1 has adopted the established variables list outlined by the second phase of the PMIP project (Braconnot et al., 2007a, b). Model outputs will be submitted and stored within the PMIP2 database. Specifically, for PlioMIP Experiment 1, this refers to PMIP2 recommended outputs for the atmosphere (outlined on the PMIP2 website http://pmip2.lsce.ipsl.fr/ > Experimental Design > Variables > Atmosphere). PMIP/PlioMIP requires participants to prepare their data files so that they meet the following constraints (regardless of the way their models produce and store their results).

Title Page
Abstract
Introduction
Conclusions
References
Tables
Figures
◀
▶
Back
Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

- The data files have to be in the (now widely used) netCDF binary file format and conform to the CF (Climate and Forecast) metadata convention (outlined on the website http://cf-pcmdi.llnl.gov/).
- There must be only one output variable per file.
- For the data that are a function of longitude and latitude, only regular grids (grids representable as a Cartesian product of longitude and latitude axes) are allowed.
- The file names have to follow the PMIP2 file name convention and be unique.

Participants are encouraged to create the files for submission to the database using the CMOR (Climate Model Output Rewriter) library. This library has been specially developed to help meet the requirements of the Model Intercomparison Projects. Details of the CMOR library are provided on the PMIP2 website (http://pmip2.lsce.ipsl.fr/ > Experimental design > Output format > CMOR library). Proposals for model analyses using PlioMIP Experiment 1 data can be made using the established protocols outlined on the PlioMIP website (http://geology.er.usgs.gov/eespteam/prism/prism_pliomip.html).

5 Conclusions

This paper provides a detailed model intercomparison project description for the Pliocene Model Intercomparison Project (PlioMIP) and documents in detail the experimental design. Specifically, this paper describes the experimental design and boundary conditions utilised for Experiment 2 of PlioMIP, following a companion paper for Experiment 1.

Acknowledgements. This work is a product of the US Geological Survey PRISM (Pliocene Research, Interpretation and Synoptic Mapping) Project and the Pliocene Model Intercomparison Project (PlioMIP), which is part of the international Palaeoclimate Modelling Intercomparison Project (PMIP). HD and MR thank the USGS Office of Global Change for their support. AH and DL acknowledge the UK Natural Environment Research Council for funding the UK contribution to PlioMIP (NERC Grant NE/G009112/1). AH acknowledges the Leverhulme Trust for their support through the award of a Philip Leverhulme Prize.

References

Braconnot, P., Otto-Bliesner, B., Harrison, S., Joussaume, S., Peterchmitt, J.-Y., Abe-Ouchi, A., Crucifix, M., Driesschaert, E., Fichefet, Th., Hewitt, C. D., Kageyama, M., Kitoh, A., Laîné, A., Loutre, M.-F., Marti, O., Merkel, U., Ramstein, G., Valdes, P., Weber, S. L., Yu, Y., and Zhao, Y.: Results of PMIP2 coupled simulations of the Mid-Holocene and Last Glacial Maximum – Part 1: experiments and large-scale features, Clim. Past, 3, 261–277, doi:10.5194/cp-3-261-2007, 2007a.

Braconnot, P., Otto-Bliesner, B., Harrison, S., Joussaume, S., Peterchmitt, J.-Y., Abe-Ouchi, A., Crucifix, M., Driesschaert, E., Fichefet, Th., Hewitt, C. D., Kageyama, M., Kitoh, A., Loutre, M.-F., Marti, O., Merkel, U., Ramstein, G., Valdes, P., Weber, L., Yu, Y., and Zhao, Y.: Results of PMIP2 coupled simulations of the Mid-Holocene and Last Glacial Maximum – Part 2: feedbacks with emphasis on the location of the ITCZ and mid- and high latitudes heat budget, Clim. Past, 3, 279–296, doi:10.5194/cp-3-279-2007, 2007b.

Dowsett, H. J., Robinson, M. M., and Foley, K. M.: Pliocene three-dimensional global ocean temperature reconstruction, Clim. Past, 5, 769–783, doi:10.5194/cp-5-769-2009, 2009.

Haywood, A. M., Dowsett, H. J., Otto-Bliesner, B., Chandler, M. A., Dolan, A. M., Hill, D. J., Lunt, D. J., Robinson, M. M., Rosenbloom, N., Salzmann, U., and Sohl, L. E.: Pliocene Model Intercomparison Project (PlioMIP): experimental design and boundary conditions (Experiment 1), Geosci. Model Dev., 3, 227–242, doi:10.5194/gmd-3-227-2010, 2010.

Kürschner, W. M., Van der Burgh, J., Visscher, H., and Dilcher, D. L.: Oak leaves as biosensors of late Neogene and early Pleistocene paleoatmospheric CO_2 concentrations, Mar. Micropaleontol., 27(1/4), 299–312, 1996.

Laskar, J., Robutel, P., Joutel, F., Gastineau, M., Correia, A. C. M., and Levrard, B.: A long term numerical solution for the insolation quantities of the Earth, Astron. Astrophys., 428, 261–285, doi:10.1051/0004-6361:20041335, 2004.

Levitus, S. and Boyer, T. P.: World Ocean Atlas 1994, Volume 2: Oxygen, NOAA Atlas NESDIS 2, US Department of Commerce, NOAA, NESDIS, 1994.

Loulergue, L., Schilt, A., Spahni, R., Masson-Delmotte, V., Blunier, T., Lemieux, B., Barnola, J. M., Raynaud, D., Stocker, T. F., and Chappellaz, J.: Orbital and millennial-scale features of atmospheric CH_4 over the past 800,000 years, Nature, 453, 383–386, 2008.

Lüthi, D., Le Floch, M., Bereiter, B., Blunier, T., Barnola, J.-M., Siegenthaler, U., Raynaud, D., Jouzel, J., Fischer, H., Kawamura, K., and Stocker, T. F.: High-resolution carbon dioxide concentration record 650 000–800 000 years before present, Nature, 453, 379–382, 2008.

Raymo, M. E., Grant, B., Horowitz, M., and Rau, G. H.: Mid-Pliocene warmth: Stronger greenhouse and stronger conveyor, Mar. Micropaleontol., 27, 313–326, doi:10.1016/0377-8398(95)00048-8, 1996.

Reynolds, R. W. and Smith, T. M.: A high-resolution global sea surface temperature climatology, J. Climate, 8, 1571–1583, 1995.

Table 1. Experimental design – PlioMIP Experiment 2

Model Coupling Atmosphere-Ocean				
Integration Length 500 yr (or as long as possible)				
Oceans				
Ocean Mode		Deep Ocean Input		
Dynamic – initialized with PRISM3 ocean temperatures if possible or Pre-Ind Control		*Global_dot_v2.0** if possible or same as Pre-Ind Control		
Preferred Boundary Conditions				
Land/Sea Mask	Topography	Ice Sheets	Vegetation	
PRISM3D (land_fraction_v1.1)	*PRISM3D (topo_v1.1*)*	*PRISM3D (biome_veg_v1.3* or *mbiome_veg_v1.3)*	*PRISM3D* or *(biome_veg_v1.3* or *mbiome_veg_v1.3*)	
Alternate Boundary Conditions				
Land/Sea Mask	Topography	Ice Sheets	Vegetation	
Local modern land/ sea mask	*PRISM3D* (*topo_v1.4**)	*PRISM3D* (*biome_veg_v1.2* or *mbiome_veg_v1.2*)	*PRISM3D* (*biome_veg_v1.2* or *mbiome_veg_v1.2*)	
Greenhouse Gases				
CO_2	N_2O	CH_4	CFCs	O_3
405 ppm	As Pre-Ind Control	As Pre-Ind Control	As Pre-Ind Control	As Pre-Ind Control
Solar Constant As Pre-Ind Control				
Aerosols As Pre-Ind Control				
Model Spin-up Documented by individual groups				

*Applied as an anomaly to control experiment data sets used by each participating group rather than as an absolute.

Title Page
Abstract Introduction
Conclusions References
Tables Figures
◀❙ ▶❙
◀ ▶
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

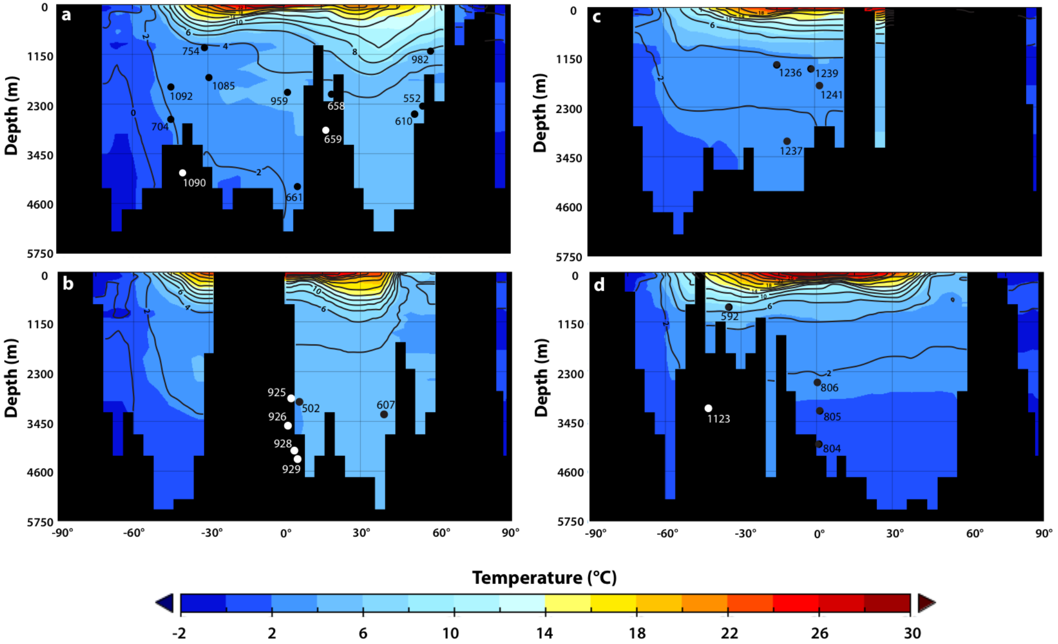

Fig. 1. Longitudinal profiles of ocean temperature from transects at **(a)** 15° W, **(b)** 45° W, **(c)** 90° W and **(d)** 165° E. All temperatures are shown in °C. Contour interval is 2 °C. Black contour lines show modern temperature overlaid on coloured regions showing the mid-Pliocene reconstruction. The change in temperature can be surmised by comparing the colour contours to the black overlaid contour lines. For example, in panel d, Site 806 is slightly cooler than 2 °C in the modern ocean but was slightly warmer than 2 °C during the mid-Pliocene (modified from Dowsett et al., 2009).

Title Page
Abstract
Introduction
Conclusions
References
Tables
Figures
◀I
I▶
◀
▶
Back
Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion