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Pliocene Model Intercomparison Project (PlioMIP): experimental design and boundary conditions (Experiment 1)

A. M. Haywood[1], H. J. Dowsett[2], B. Otto-Bliesner[3], M. A. Chandler[4,5], A. M. Dolan[1], D. J. Hill[6], D. J. Lunt[6,7], M. M. Robinson[2], N. Rosenbloom[3], U. Salzmann[6], and L. E. Sohl[4,5]

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

[6]British Antarctic Survey, High Cross, Madingley Road, Cambridge, Cambs, CB3 0ET, UK
[7]School of Geographical Sciences, Univ. of Bristol, University Road, Bristol, BS8 1SS, UK

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

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Abstract

In 2008 the temporal focus of the Palaeoclimate Modelling Intercomparison Project was expanded to include a model intercomparison for the mid-Pliocene warm period (ca. 2.97 to 3.29 Ma BP). This project is referred to as PlioMIP (Pliocene Model Intercomparison Project). Two experiments have been agreed upon and comprise phase 1 of the PlioMIP. The first (Experiment 1) will be performed with atmosphere-only GCMs. The second (Experiment 2) will utilise fully coupled ocean-atmosphere GCMs. This paper describes the experimental design and boundary conditions that will be utilised for Experiment 1 of the PlioMIP project.

1 Introduction

1.1 The mid-Pliocene warm period

The mid-Pliocene warm period (MPWP) is defined by the United States Geological Survey's PRISM Group (**P**liocene **R**esearch **I**nterpretation and **S**ynoptic **M**apping; http://geology.er.usgs.gov/eespteam/prism/index.html) as the interval between 3.29 and 2.97 Ma (according to the geomagnetic polarity timescale of Berggren et al., 1995), lying between the transition of oxygen isotope stages M2/M1 and G19/G18 (Shackleton et al., 1995), in the middle part of the Gauss Normal Polarity Chron (Dowsett et al., 1999). The "Time Slab" represents a climatically distinct period during the Pliocene when Earth's climate was, on the whole, warmer than present (Dowsett et al., 1999; Dowsett, 2007a).

The MPWP has been the subject of intense study for the last two decades. There are many reasons for this, but the most important driver has been our desire to understand the dynamics of past warm climates as a potential guide to understanding climate change in the future (Haywood et al., 2009). The MPWP is well suited to this task. The climatic signal (change from modern) is sufficiently large, for many geographical regions, to be differentiated from the noise generated by the uncertainties and limitations inherent in the techniques used for palaeoclimatic/palaeoenvironmental reconstruction. The interval was the last time in Earth history when global temperatures were significantly warmer than modern, over a period longer than any Quaternary interglacial. It is unique in that continental configurations were relatively unchanged from today, and geological proxies are superior to those of preceding warm periods due to improved geographic coverage, more reliable biota-environment correlations and higher resolution stratigraphy (Dowsett, 2007a).

1.2 Palaeoclimate modelling, PMIP and PlioMIP

General Circulation Models (GCMs) are now routinely used to simulate and predict Earth's present and future climate (e.g. Solomon et al., 2007). Although there is broad agreement among the models, there are also significant differences in the details of their predictions (Randall et al., 2007). Numerous palaeoclimate simulations have been conducted for various intervals in Earth History (e.g. Kutzbach and Otto-Bliesner, 1982; Barron and Washington, 1982; Valdes and Sellwood, 1992; Kim and Crowley, 2000; DeConto and Pollard, 2003; Huber and Caballero, 2003; Haywood et al., 2007; Sohl and Chandler, 2007). In part, these studies are being carried out in an effort to determine whether or not GCMs can successfully retrodict climatic conditions significantly different from present day. Through comparison with geological proxy data, such studies may provide us with more confidence in climate model simulations for the future (Williams et al., 2007 and chapters therein). However, it has been the norm in palaeoclimate modelling studies for only a single model to be used in any one study, meaning the degree to which the results are model dependent is often not addressed.

Exceptions to this norm are the modelling studies carried out as part of the **P**alaeoclimate **M**odelling **I**ntercomparison **P**roject (PMIP), which was initiated in order to co-ordinate and encourage the systematic study of GCMs and to assess their ability to simulate large differences of climate that occurred in the past (e.g. Joussaume and Taylor, 1995; Braconnot et al., 2007a, b). It has also served to encourage the preparation of global reconstructions of palaeoclimates that can be used to evaluate climate models (e.g. Prentice and Webb, 1998). The temporal focus of the studies carried out by PMIP phases I and II was restricted to the Last Glacial Maximum and the mid-Holocene climatic optimum, for which detailed reconstructions of palaeoenvironmental conditions exist in a suitable format for integration with GCMs (e.g. Peltier ICE5G, BIOME6000, MARGO and CLIMAP). However, at a meeting to discuss the scientific agenda for PMIP Phase III, held in September 2008 in Estes Park Colorado (a summary of which can be found in Otto-Bliesner et al., 2009), it was decided to expand the temporal range of PMIP to include the 8.2 kyr event, the Last Interglacial and the Mid-Pliocene Warm Period (MPWP).

For the initial phase of the MPWP model intercomparison (hereafter refereed to as PlioMIP (**Plio**cene **M**odel **I**ntercomparison **P**roject) two experiments were agreed upon. The first is an experiment using atmosphere-only models (hereafter referred to as Experiment 1), whilst the second experiment (hereafter referred to as Experiment 2) will utilise coupled Ocean-Atmosphere General Circulation Models (OAGCMs). 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 and will describe, (a) the chosen experimental design for Experiments 1 and 2, (b) a detailed description of the boundary conditions used in both experiments, and (c) contributions from participating modelling groups that describe how the boundary conditions were implemented into their own climate models, along with the basic results from the experiments themselves. This detailed record for the rationale and specifics of the experimental design, construction of the boundary conditions data sets, and critically, how these were implemented into each climate model, will provide an invaluable reference when the intercomparison phase of PlioMIP is reached, helping the PlioMIP/PMIP community more easily understand the differences which will inevitably be observed between MPWP simulations. The purpose of this paper is to describe the experimental design and boundary conditions for PlioMIP Experiment 1.

2 Experimental design – Experiment 1

2.1 Integration length, atmospheric gasses/aerosols, solar constant/orbital configuration

The experimental design for Experiment 1 is summarised in Table 1. The experiment integration length was set at 50 years. Given the specified SSTs and quick response time of the atmosphere, this integration length will enable even the slowest responding elements of the system in an AGCM experiment, such as deep soil moisture, to reach full equilibrium. The first 20 years of the simulations will be considered as spin-up. The concentration of CO_2 in the atmosphere was set at 405 ppmv which is a little more than the median of the plausible range of palaeo 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 in Quaternary ice core records (e.g. Loulergue et al., 2008; Lüthi et al., 2008). In the absence of any proxy data to the contrary, 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 a time slab (2.97 to 3.29 Ma) rather than a discreet time slice, making it challenging to prescribe an orbital configuration which is representative of the entire ~300 000 year interval. Furthermore, it is difficult to provide an average insolation forcing at the top of the atmosphere in some GCMs, with some models requiring specific values for eccentricity, obliquity and precession. Therefore, PlioMIP decided to specify a Modern orbital configuration (1950 AD), even though available astronomical solutions (e.g. Laskar et al., 2004) indicate that this may not be an ideal approach given that the MPWP is a time slab (Fig. 1, see Sect. 3.4). However, a Modern orbit is close to the average MPWP forcing at 65° N in July.

2.2 Implementation of sea-surface temperatures and topography as an anomaly

To ensure that the climate anomalies (mid-Pliocene minus present day) 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 SSTs as an anomaly to whatever standard modern SST and topographic data set is used by each modelling group in their own model. To create the Pliocene SST/topography the difference between the PRISM_Pliocene and PRISM_Modern topography/SST is added to the modern SST and topographic data sets each participating modelling group employs.
Such that:

Topo_Plio=(Orog_Plio_PRISM3D−Topo_Modern_PRISM3D) + Topo_Modern_Local

and

SST_Plio=(SST_Plio_PRISM3D−SST_Modern_PRISM3D) + SST_Modern_Local

Local = standard present-day topography/SSTs used by each participating group.

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/SST in regions where no modern data is given (such as for the Pliocene topography in the Hudson Bay region). Also Modern SST are projected onto the two mid-Pliocene land-sea masks ("preferred" and "alternate", see Sect. 2.3) in regions where no SST data is given to produce the modern SST datasets in order to make the SST anomalies easier to generate consistently.

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

Two boundary condition data packages are available – "preferred" and "alternate". The preferred data package requires the ability to change the models land/sea mask to a mid-Pliocene configuration. The alternate data package, with a modern land/sea configuration, are produced in order to maximise the potential number of participating groups in PlioMIP, since it is difficult in some GCMs 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 GCMs.

3 Description of boundary conditions (PRISM3D)

All boundary condition files and details of experimental design that are necessary to successfully complete PlioMIP Experiment 1 (both for the preferred and alternate boundary condition configuration) can be found (permanently) on the US Geological Survey-based PlioMIP website: http://geology.er.usgs.gov/eespteam/prism/prism_pliomip_data.html.

3.1 Land-sea mask and topography (outside of ice-sheet regions)

The PRISM3D/PlioMIP land/sea mask and topographic reconstruction is provided in both netCDF format and as an Excel spreadsheet at a $2^\circ \times 2^\circ$ resolution. In contrast to the land/sea mask presented in older PRISM2 reconstruction of Dowsett et al. (1999), the PRISM3D land/sea mask is fractional. Continental and oceanic regions are 100% land and ocean respectively, but the margin between these areas is fractional. Areas with only land are given land cover (biome and mega-biome see Sect. 3.6) classification, and topography. Ocean only areas have sea surface temperatures. Fractional land-sea regions (coastal areas) are given all relevant data types. A representation of the PRISM3D/PlioMIP fractional data system is provided in Fig. 2.

In PRISM3D global sea-level is estimated to be 25 metres higher than modern. This is consistent with evidence from palaeoshorelines (e.g. the Orangeburg Scarp along the US Atlantic Coastal Plain; Dowsett and Cronin, 1990) and the results of numerical ice sheet models (Hill et al., 2007; Hill, 2009; Pollard and DeConto, 2009, see Sect. 3.3).

To create a coastline which reflected a 25 m sea-level rise, an ocean mask derived from the ETOPO5 data set (NOAA, 1988) was superimposed over the modern continental outline. The Hudson Bay was in-filled at low elevation due to this feature being derived largely from glacial erosion during the Pleistocene. The West Antarctic Ice Sheet is absent (Pollard and DeConto, 2009, see Sect. 3.3) which creates ocean in locations where the current bed-rock elevation is less than 25 m higher than modern sea-level. The fractional land/sea mask and topographic reconstruction is shown in Fig. 3.

The basic PRISM3D/PlioMIP topographic reconstruction is based on the Pliocene palaeogeography of Markwick (2007), which introduces greater detail in the topography (especially in the 0 to 500 m range) than was available in the PRISM2 topographic data set (Thompson and Fleming, 1996; Dowsett et al., 1999). In PRISM2 the western cordillera in northern South America and in the Rocky Mountains/Colorado Plateau was reduced by 2000 and 1500 m respectively to ~50% of the modern elevation (Thompson and Fleming, 1996). More recent studies by Garzione et al. (2006), Ghosh et al. (2006), Rowley and Garzione (2007) and McMillan et al. (2006) suggest that such a large reduction in elevation is unlikely at ca. 3 Ma, thus the Rocky Mountains and Andes are specified at approximately their current elevations in PRISM3D. Further details of the PRISM3D/PlioMIP land/sea mask and topographic reconstruction can be found in Sohl et al. (2009).

3.2 Ice-sheet height and extent

The direct geological evidence for ice sheets in the Pliocene is sparse and, when inferences are made about the wider cryosphere, seemingly inconsistent. Previous iterations of the PRISM data set (i.e. PRISM2) included ice sheet reconstructions based on sea-level data and marine isotope ratios and idealised ice sheet modelling (Dowsett and Cronin, 1990; Dowsett et al., 1999). Whilst this provided a reasonable initial approximation, the uncertainties in the data, and thus in the reconstructions themselves, are large (Krantz, 1991). Furthermore, while overall ice volumes can be estimated from proxy data, the proxies can not differentiate between different potential ice sheet locations.

New ice sheet estimates were produced from high-resolution ice sheet model experiments performed with the British Antarctic Survey Ice Sheet Model (BASISM), utilising Hadley Centre GCM climatologies produced with PRISM boundary conditions (Hill et al., 2007; Hill, 2009). This has the distinct advantage of producing ice sheets consistent with both known atmospheric and glaciological physics and the PRISM palaeoenvironmental reconstruction. The climate simulation chosen for these ice sheet reconstructions is the same as that chosen for the PRISM3D vegetation reconstruction (Salzmann et al., 2008, see Sect. 3.5), thus providing consistency both within the new palaeoenvironmental data set and with mid-Pliocene vegetation changes.

The PRISM3D ice sheet reconstruction shows significant changes from the modern ice sheets over Greenland and Antarctica. On Greenland, the ice sheet extent is much reduced, with ice restricted to the high-altitude regions of East Greenland. In East Antarctica, while large portions of the ice sheet show little change or a small increase in surface altitude, significant ice-sheet retreat occurs in the Wilkes and Aurora Subglacial basins. These areas are currently below sea-level and largely unconstrained by topography, so provide a good candidate for East Antarctic Ice Sheet retreat. West Antarctica has not been modelled in these experiments, as all the major mechanisms of marine ice-sheet retreat have yet to be robustly included in ice sheet models (Vieli and Payne, 2005). However, recent ANDRILL core data and ice sheet modelling (Naish et al., 2009; Pollard and DeConto, 2009) suggests that, at least in the warmest periods of the Pliocene, there was no ice present in West Antarctica. Combining this assumption with our models of Greenland and East Antarctica predicts ice sheet retreat of over 22 m sea-level equivalent, in good agreement with eustatic sea-level estimates.

3.3 Sea-surface temperatures

The PRISM3D sea-surface temperature field is presented on the same 2°×2° resolution fractional grid described in Sect. 3.1 as a series of 12 monthly SST fields in netCDF or Excel format. PRISM3D SST differs from PRISM2 SST (Dowsett et al., 1999; Dowsett, 2007a) by taking into account data from more localities, particularly in the equatorial Pacific (Dowsett, 2007b; Dowsett and Robinson, 2009) and North-eastern Atlantic/Arctic regions (Robinson, 2009; Robinson et al., 2008; Dowsett et al., 2009a, b). In addition, PRISM3D incorporates for the first time multiple temperature proxies (multivariate analysis of fossil planktonic foraminfers, ostracods, and diatoms as well as Mg/Ca and alkenone unsaturation index palaeothermometry) which provide greater overall confidence in the SST fields.

In order to provide a single temperature value at each locality PRISM uses a warm-peak averaging (WPA) technique whereby time-series data are analysed and warm peaks are averaged. Details of the technique can be found in Dowsett and Poore (1991), Dowsett (2007a) and Dowsett and Robinson (2006). A late Pleistocene analogy would be to average the temperatures from peak interglacials at marine isotope stages 5e, 7 and 9 to generate a single representative “interglacial temperature estimate” for a particular location.

Once February (August) temperature estimates are determined for each locality using WPA, the estimates are differenced from modern temperature (Reynolds and Smith, 1995) to create SST anomalies (Figs. 5 and 6). These anomalies are superimposed on a modern SST map for February (August) and the anomaly patterns are extrapolated globally using the distribution of actual data points and the modern SST field and its gradients as a guide. This new anomaly field is then added to the modern SST fields of Reynolds and Smith (1995) (= SST_Modern_PRISM3D; Sect. 2.2 above) to create Pliocene February (August) SST (= SST_Plio_PRISM3D; Sect. 2.2 above).

In many regions of the present day ocean, the annual SST cycle can be approximated by a sine curve. While this is not true everywhere, PRISM3D utilises a sine curve fit to February and August SST to generate twelve months of SST data.

The PRISM3D SST reconstruction shows little warming in low latitudes relative to late 20th century conditions, and increased warming at higher latitudes (Fig. 6). In the Northern Hemisphere the Kuroshio and Gulf Stream/North Atlantic Drift currents are regions of significant warm anomalies. Oceanographic fronts are generally displaced toward the polar regions and the zonally averaged pole to equator temperature gradient is reduced relative to present day.

3.4 Sea-ice extent

Sea-ice cover is part of the PRISM3D SST data set (Fig. 6). Southern Hemisphere sea-ice extent is determined by mid-Pliocene distribution of key diatom taxa (Barron, 1996a, b; Dowsett et al., 1996). Assuming an ice-free summer and maximum sea-ice extent governed by the diatom data, modern seasonal patterns of sea-ice waxing and waning were used to describe the Pliocene seasonal changes in sea ice. These data were further adjusted to fit available SST data in the Southern Ocean.

There is no direct evidence for mid-Pliocene sea ice extent in the Northern Hemisphere. However, extreme warmth documented in marine and terrestrial sequences in the Arctic argues for at least seasonally ice-free conditions (Brouwers, 1994; Cronin et al., 1993; Robinson, 2009; Matthiessen et al., 2009). In a fashion similar to the method used in the Southern Hemisphere, modern seasonal growth patterns of sea-ice were used to expand and contract the ice margin from it's mid-Pliocene maximum extent (= modern summer extent) to a summer ice-free condition. This monthly distribution was further modified by available SST data.

3.5 Vegetation type and distribution

The PRISM3D vegetation reconstruction is based on an approach which combines an internally consistent dataset of 202 palaeobotanical sites with predictions from a coupled climate-vegetation model (Fig. 7; Salzmann et al., 2008). By using the 28-biome classification scheme of the BIOME4 mechanistic model of vegetation (e.g. Prentice et al., 1992), the new Pliocene vegetation reconstruction is fully compatible with BIOME4 model outputs which facilitates comparison of proxy data and climate model/BIOME4 simulations. It is also more detailed than the previous PRISM2 vegetation reconstruction (Thompson and Fleming, 1996), which is based on a 7-type land cover classification scheme, palaeobotanical records from 74 sites and, in some cases, modern vegetation to fill data sparse regions. A full description of the new data-model hybrid and data-model coupling strategy including a complete list of palaeobotanical literature used for the biome reconstruction can be found in Salzmann et al. (2008).

In brief, Salzmann et al. (2008) compiled data from literature covering the Piacenzian stage (~3.6–2.6 Ma) and translated them into the BIOME4 scheme using the authors' interpretation taken from the original research paper. A comprehensive GIS database was designed to synthesize and compare the output of our data-based biome reconstruction with predictions of the mechanistically based BIOME4 vegetation model forced by climatology derived from a standard mid-Pliocene Hadley Centre atmospheric model version 3 (HadAM3) GCM simulation (Haywood and Valdes, 2006). As the model simulation provides a much closer approximation to the true mid-Pliocene condition than modern vegetation, we used the BIOME4 output as a guide to interpolate and reconstruct vegetation for data-sparse regions.

The PRISM3D Pliocene vegetation reconstruction is available as a 28-type biome or a 9-type mega-biome map on a $2^\circ \times 2^\circ$ fractional land grid in netCDF or Excel spreadsheets format (Fig. 8). Mega-biomes were classified after Harrison and Prentice (2003). The vegetation zonation reconstructed for the Piacenzian stage indicates a generally warmer and moister climate than today. Most prominent changes in biome distribution compared to today include a northward displaced evergreen taiga by more than 10 degrees, resulting in a significantly reduced area of tundra vegetation. The northward shift suggests that the polar regions were 10 to 15°C warmer as annual mean relative to today. The vegetation change was accompanied by a parallel northwards expansion of temperate forests and grasslands in Russia and eastern North America replacing boreal conifer forests. Further south, diverse warm-temperate forests with East Asian and North American affinities became dominant in central Europe. A wetter Pliocene climate also resulted in the expansion of tropical savannas and woodland in Africa and Australia at the expense of deserts.

3.6 River routing, soils and lakes

With regard to river routing, "standard" and "minimum" solutions are specified. The standard solution is to alter the river routes to follow the steepest gradient in mid-Pliocene topography. The minimum solution is to follow modern river routes except where inappropriate due to changes in the mid-Pliocene land/sea mask where rivers should be routed to the nearest ocean grid box. For soils two options are specified. Option 1 ("preferred") states that soil types and distribution can be specified in a way that is consistent with the imposed Pliocene vegetation distribution (see Sect. 3.5). Option 2 ("alternate") specifies soil types and distribution as modern. In areas where land has been created in the Pliocene reconstruction compared to the modern land/sea mask, soil type should be extrapolated from the nearest modern grid box.

MPWP lakes are specified as being absent. The Salzmann et al. (2008) land cover reconstruction does not include any information on Piacenzian Stage lake distribution and/or size. Lake distributions will be incorporated into the PRISM4 version of the Salzmann et al. (2008) land cover reconstruction using a combination of collated sedimentary evidence and analyses of multi-model predicted mean annual Precipitation minus Evaporation balance (P−E; where a positive multi-model mean P−E indicates conditions suitable for the maintenance of lakes).

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. Model outputs will be submitted and stored within the PMIP 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). The PMIP/PlioMIP project 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).

- 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.
- 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 library (Climate Model Output Rewriter). 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).

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Table 1. Experimental design – PlioMIP Experiment 1.

Model Coupling				
Atmosphere-Only				
Integration Length				
50 years				
Oceans				
	Ocean Mode		**Deep Ocean Input**	
	Specified SST Climatology		*none*	
Preferred Boundary Conditions				
Land/Sea Mask	Topography	Ice Sheets	Vegetation	SST
PRISM3D *(land_fraction_v1.1)*	*PRISM3D* *(topo_v1.1*)*	*PRISM3D* *(biome_veg_v1.3* or *mbiome_veg_v1.3)*	*PRISM3D* *(biome_veg_v1.3* or *mbiome_veg_v1.3)*	*PRISM3D* *(PRISM3_SST_v1.1*)*
Alternate Boundary Conditions				
Land/Sea Mask	Topography	Ice Sheets	Vegetation	SST
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)*	*PRISM3D* *(PRISM3_SST_v1.3*)*
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				
Orbital Parameters				
As Pre-Ind Control				

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

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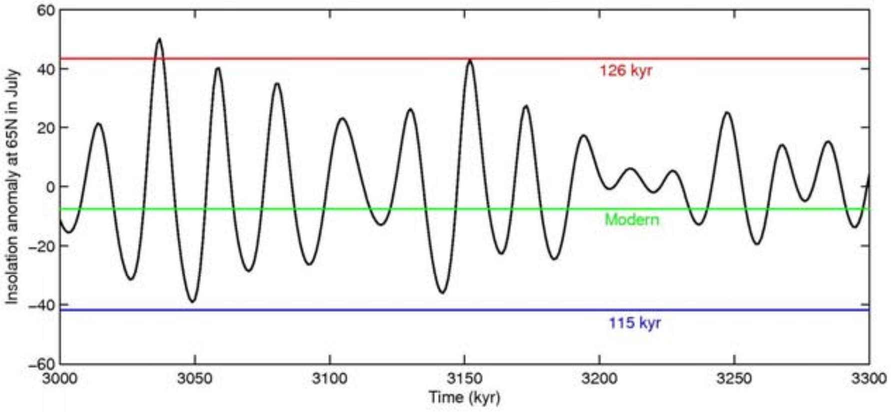

Fig. 1. Calculated insolation anomaly (from the mean Mid-Pliocene Warm Period value) at the top of the atmosphere (TOA) at 65° N in July derived from the Laskar04 solution (Laskar et al., 2004). Insolation values for the Modern (2000 AD), 126 kyr (peak of the Last Interglacial) and 115 kyr (Last Glacial Inception Period) are added for reference.

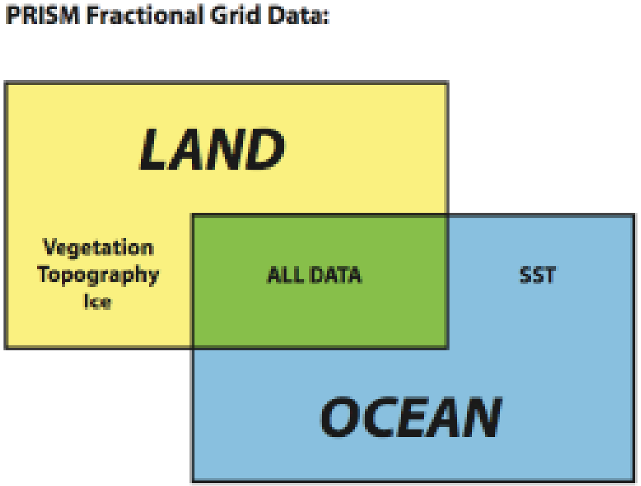

Fig. 2. Schematic representation of the PRISM3D/PlioMIP fractional grid data approach.

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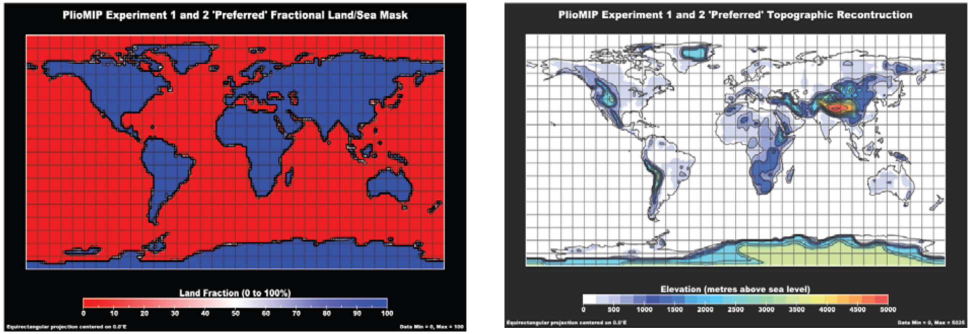

Fig. 3. "Preferred" fractional land/sea mask (left) with mid-Pliocene topography (right) for use in Experiment 1 and 2 (Sohl et al., 2009). Basic palaeogeographic reconstruction derived from Markwick (2007), modified to account for ice sheet model-predicted ice sheet extent and height above sea-level (see Sect. 3.2).

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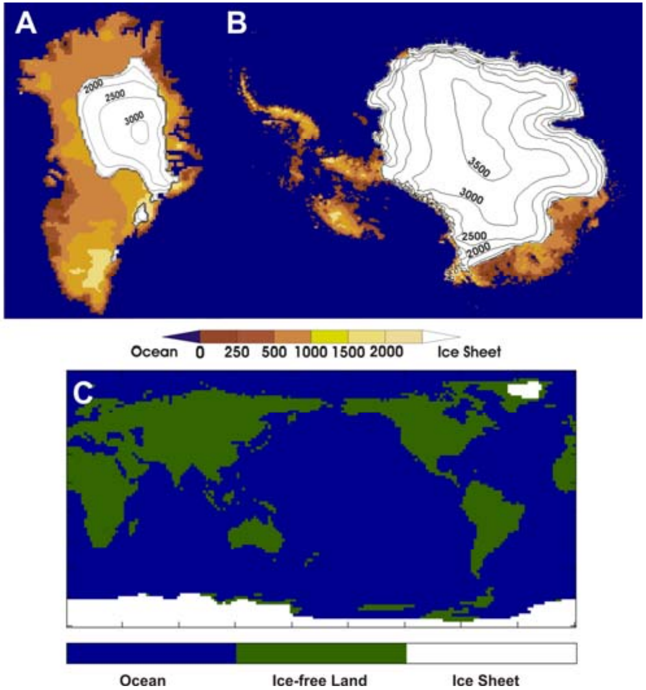

Fig. 4. PRISM3D mid-Pliocene warm period ice sheet reconstructions (Hill et al., 2007; Hill, 2009; Salzmann et al., 2008) for the Greenland **(A)** and Antarctic **(B)** ice sheets and their extent on the PRISM3D global grid **(C)**

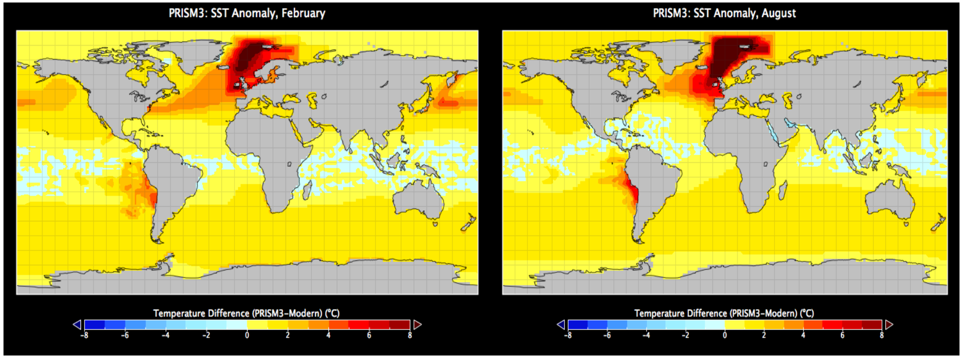

Fig. 5. PRISM3D SST anomaly for February (left) and August (right).

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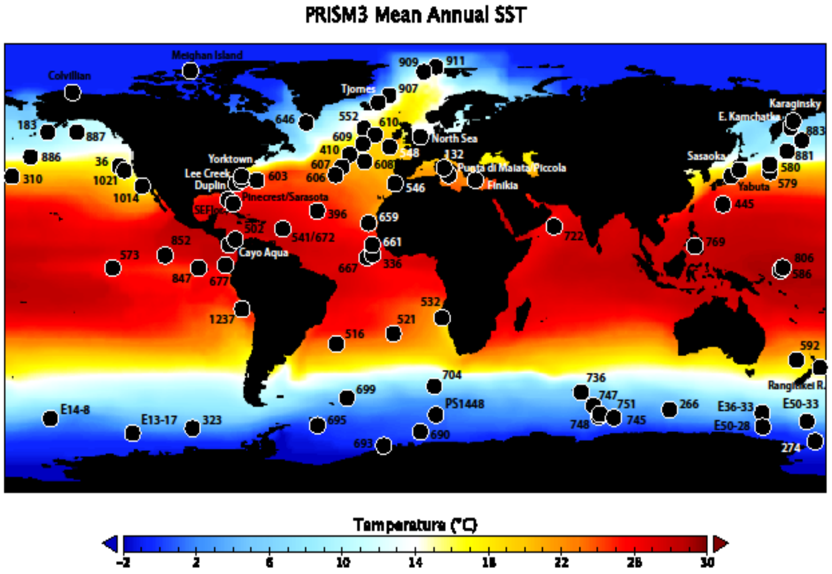

Fig. 6. PRISM3D mean annual SSTs and site localities.

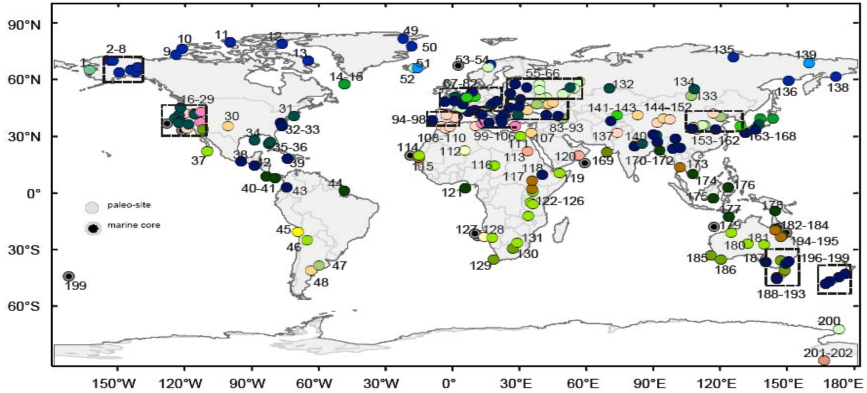

Fig. 7. Geographical distribution of 202 palaeobotanical sites used in the Salzmann et al. (2008) reconstruction of global Piacenzian Stage land cover.

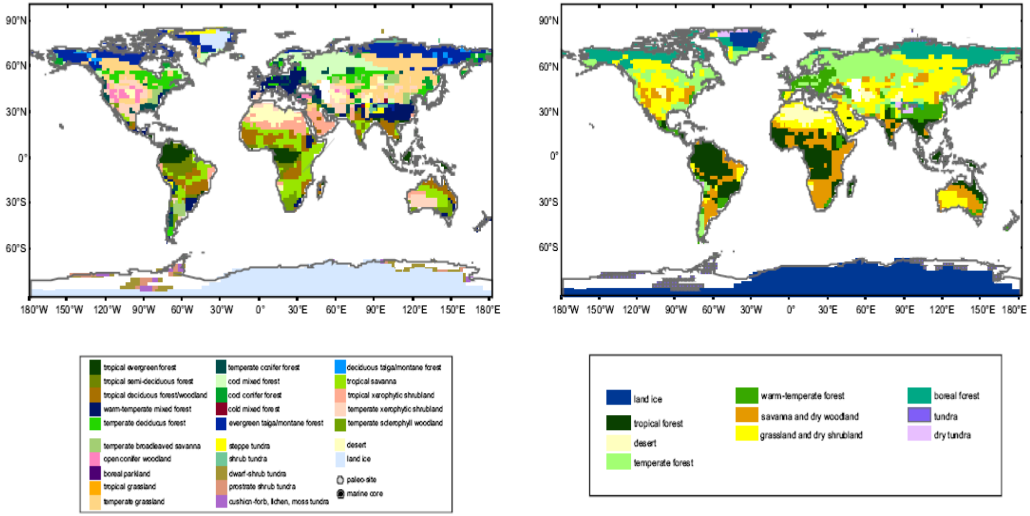

Fig. 8. The PRISM3D land cover data/model hybrid (Salzmann et al., 2008). Left: displayed using the full BIOME4 classification scheme. Right: displayed using the BIOME4 mega-biome scheme.

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