Simulating the Mid-Pliocene Warm Period: how similar are the models?

Haywood, A. M.[1], Bonham, S.[1]*, Chandler, M. A.[2], Valdes, P. J.[3], Salzmann, U.[4], Lunt, D. J.[3], Otto-Bliesner, B.[5], Rosenbloom, N.[5] and Dowsett, H. J.[6]

1. School of Earth and Environment, Univ. Leeds; 2. Goddard Institute for Space Studies; 3. School of Geographical Sciences, Univ. Bristol; 4. British Antarctic Survey; 5. National Center for Atmospheric Research; 6. US Geological Survey

The mid-Pliocene Warm Period (MPWP, ca. 3.3 - 3 million years ago) provides an unparalleled opportunity to examine the long term response of the Earth System to elevated greenhouse gas concentrations. The MPWP has become an important target for palaeoclimate modelling, with a large number of studies published during the last decade. However, there has been no attempt to assess the degree of model dependency of the results obtained. Here we present a comparison of mid-Pliocene climatologies produced by the Goddard Institute for Space Studies (GISS), Hadley Centre for Climate Prediction and Research and National Center for Atmospheric Research (NCAR) atmosphere-only General Circulation Models (GCMAM3, HadAM3 and CAM3-CLM). A terrestrial data/model comparison was made using the BIOME 4 model and a new data set of Piacenzian Stage land cover (Salzmann et al., 2008), combined with the use of Kappa statistics. The results indicate that the HadAM3 and CAM3-CLM predicted biomes provide a closer fit to proxy data in the mid to high-latitudes, however, GCMAM3 predicted biomes provide the closest fit to proxy data in the tropics. This study is a contribution to the newly established Pliocene Climate Modelling Intercomparison Project (Plio-MIP), which is part if the Palaeoclimate Modelling Intercomparison Project (PMIP).

1. Introduction and Rationale

General Circulation Models (GCMs) are regularly used to simulate and predict Earth's present and future climate (e.g. IPCC, 2007). Although there is broad agreement among the models, there are significant differences in the details of their predictions (Randall et al., 2007) and the degree to which the results are model dependent is often not addressed. PMIP was initiated in order to co-ordinate and encourage the study of GCMs and assess their ability of simulating large differences of past climate (e.g. Joussaume and Taylor, 1995; Hoar et al., 2004; Zheng et al., 2008).

The mid-Pliocene warm period is the most recent interval of greater global warmth, characterised by global surface temperatures ~3 ºC higher than pre-industrial (e.g. Haywood and Valdes 2004). At this time, the continents and ocean basins had their present geographic configuration, which provides a view of the equilibrium state of a globally warmer world, in which atmospheric CO_2 concentrations (estimated to be between 360-400 ppm) were likely higher than pre-industrial values (Jansen et al., 2007). The recent Intergovernmental Panel on Climate Change (IPCC) 4th assessment report states that the mid-Pliocene Climate represents an "accessible example of a world that is similar in many respects to what models estimate could be the Earth of the late 21st century" (Jansen et al., 2007).

2. Methodology

• HadAM3; developed at the Hadley Centre for Climate Prediction and Research (see Pope et al., 2000).
• The GISS Global Climate Middle Atmosphere Model version 3 (GCMAM3) (see Rind et al. 2007).
• NCAR Community Atmosphere Model (Collins et al., 2006) coupled with the Community Land Model (Dickinson et al., 2006) (CAM3-CLM)

GCM	Model resolution	Solar constant (Wm^{-2})	Eccentricity	Obliquity	Precession	Sea-ice leads fraction (%)
HadAM3	2.5° × 3.75°	1365	0.0167	23.44	282.9	10 (via seaice input files)
GCMAM3	4° × 5°	1365	0.0167	23.44	282.9	5
CAM3-CLM	2.8° x 2.8°	1365	0.0167	23.44	282.9	-

Table 1: Dynamical characteristics, parameterisations and resolution for HadAM3, GCMAM3 and CAM3-CLM.

Simulation Name	Integration length (yrs)	Averaging period (yrs)	Land/sea mask & topography	SSTs	Land and sea-ice	Land cover	CO_2 ppmv	CH_4 ppbv	N_2O ppbv	CFC^{11} pptv	CFC^{12} pptv
$HadAM3^{PD}$	30	10	ETOPO5 (NOAA, 1988)	Reynolds & Smith (1995)	Jasperson et al. (1990)	Wilson & Henderson-Sellers (1985)	346	790	285	222	382
$HadAM3^{MP}$	20	12	PRISM2	PRISM2	PRISM2	PRISM2	315	1250	287	0	0
$GCMAM3^{PD}$	20	12	NASA/GISS from ETOPO5	Rayner et al. (2003)	Land ice: ETOPO5 (NOAA, 1988) Sea-ice: Rayner et al. (2003)	Matthews (1985) Abramopolous et al. (1988)	315	1200	287	0	0
$GCMAM3^{MP}$	20	12	PRISM2	PRISM2	PRISM2	PRISM2	315	1250	287	0	0
$CAM3\text{-}CLM^{PD}$	40	20-39	PRISM2	CCSM	PRISM2	PRISM2	346	790	285	0	0
$CAM3\text{-}CLM^{MP}$	40	20-39	PRISM2	PRISM2	PRISM2	PRISM2	315	1250	287	0	0

Table 2: Details on model resolution, experiment types with initial conditions and boundary condition details provided.

3. Climatologies

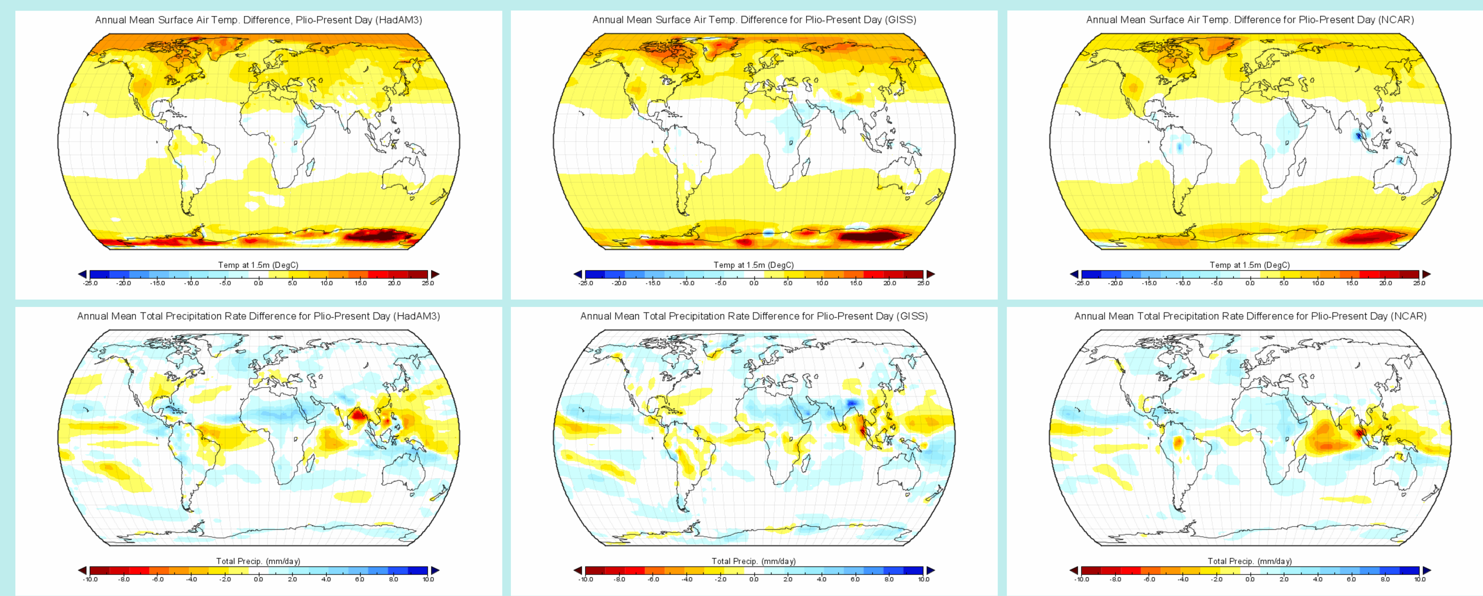
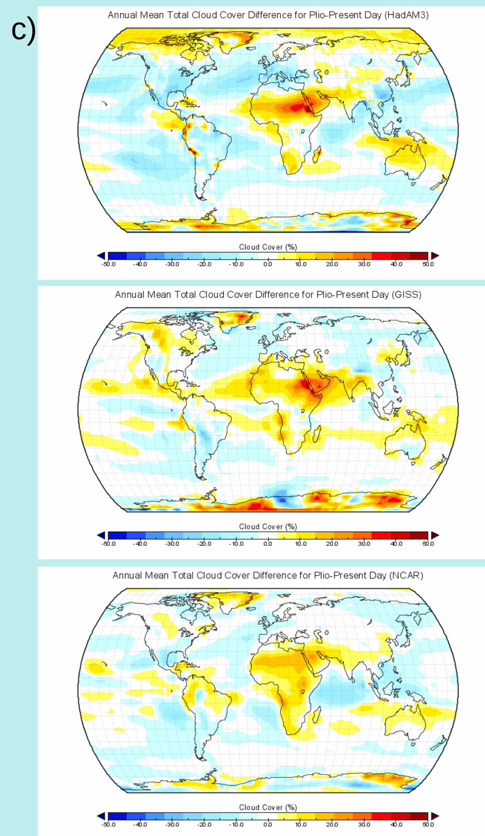



Figure 1.a) Annual mean difference (mid-Pliocene minus present-day) in surface air temperature (°C), b) total precipitation rate (mm/day) and c) total cloud cover (%) predicted by the HadAM3, GCMAM3 and CAM3-CLM models.

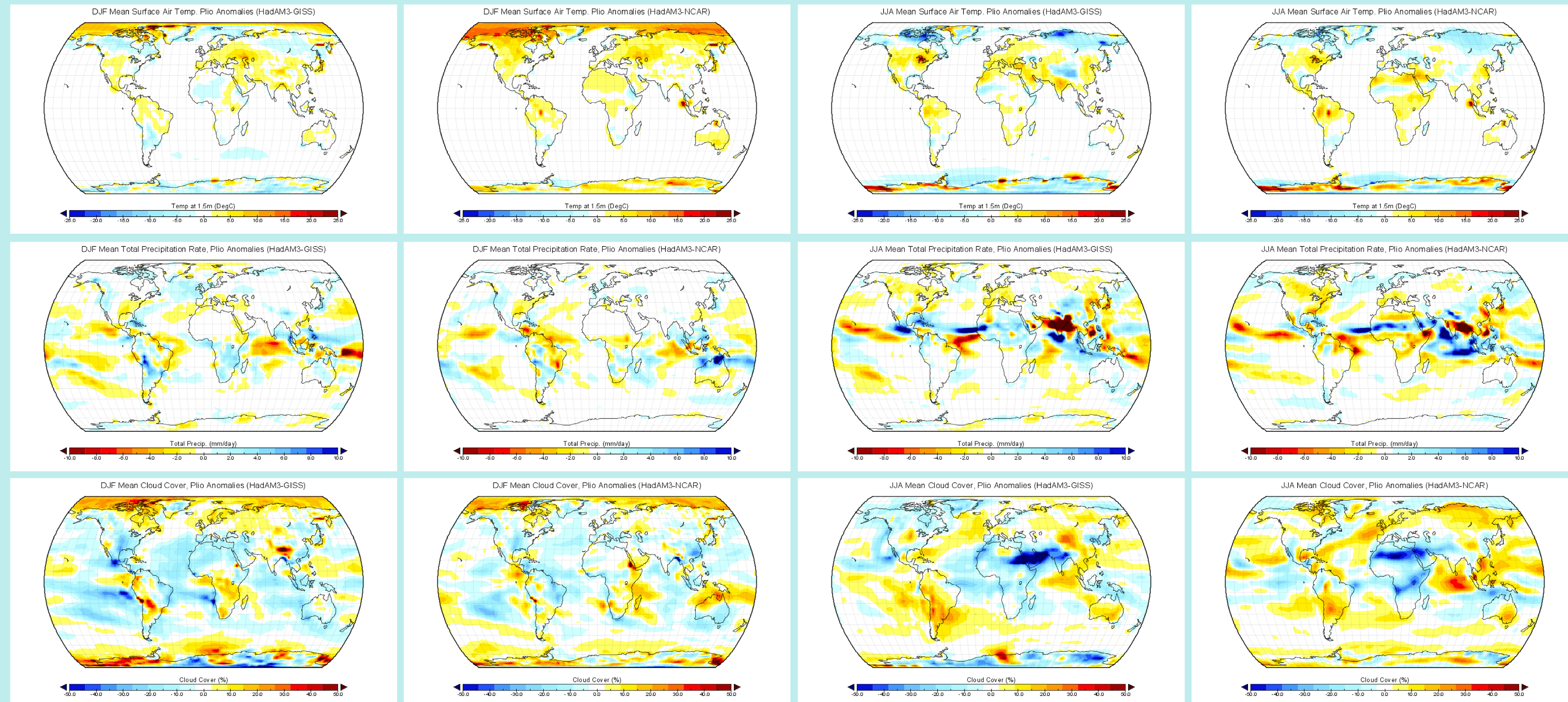
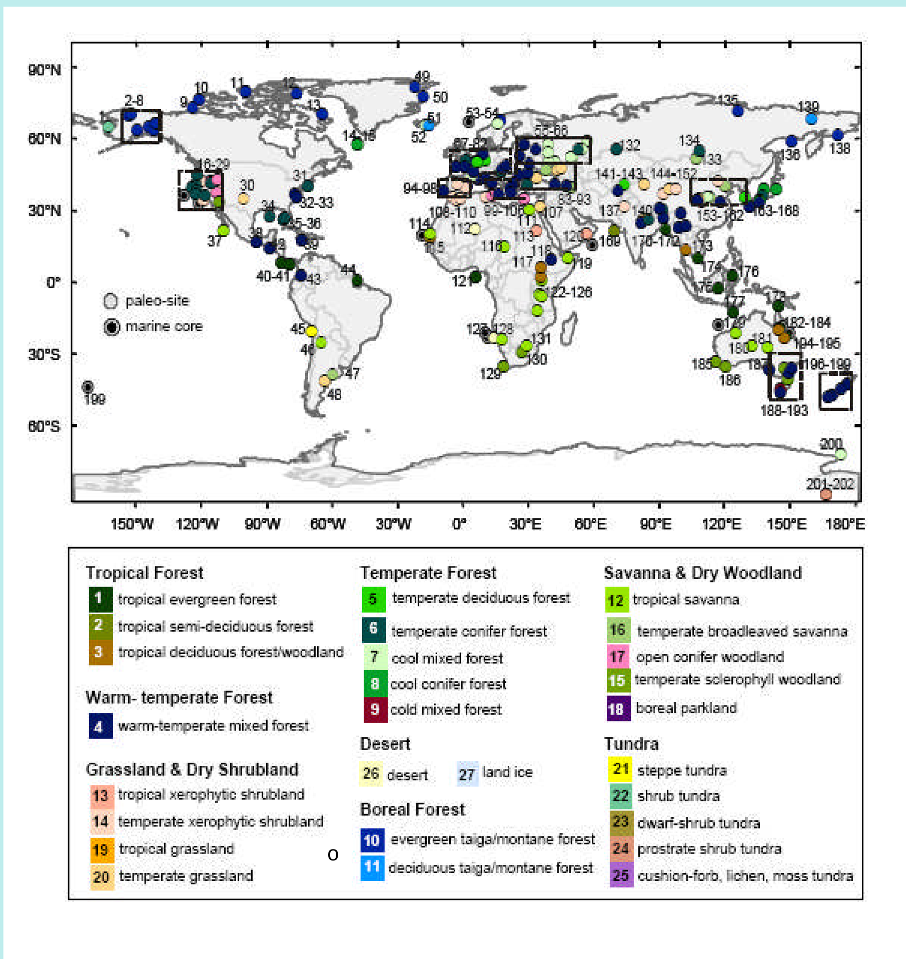


Figure 2. Differences in mid-Pliocene anomalies (HadAM3 mid-Pliocene minus HadAM3 present-day; minus GCMAM3 mid-Pliocene minus GCMAM3 present-day and CAM3-CLM mid Pliocene minus CAM3-CLM present day) December, January and February (DJF) and June, July and August (JJA), surface air temperatures (°C), total precipitation rate (mm/day) and cloud cover (%).

4. Data-Model Biome Comparison



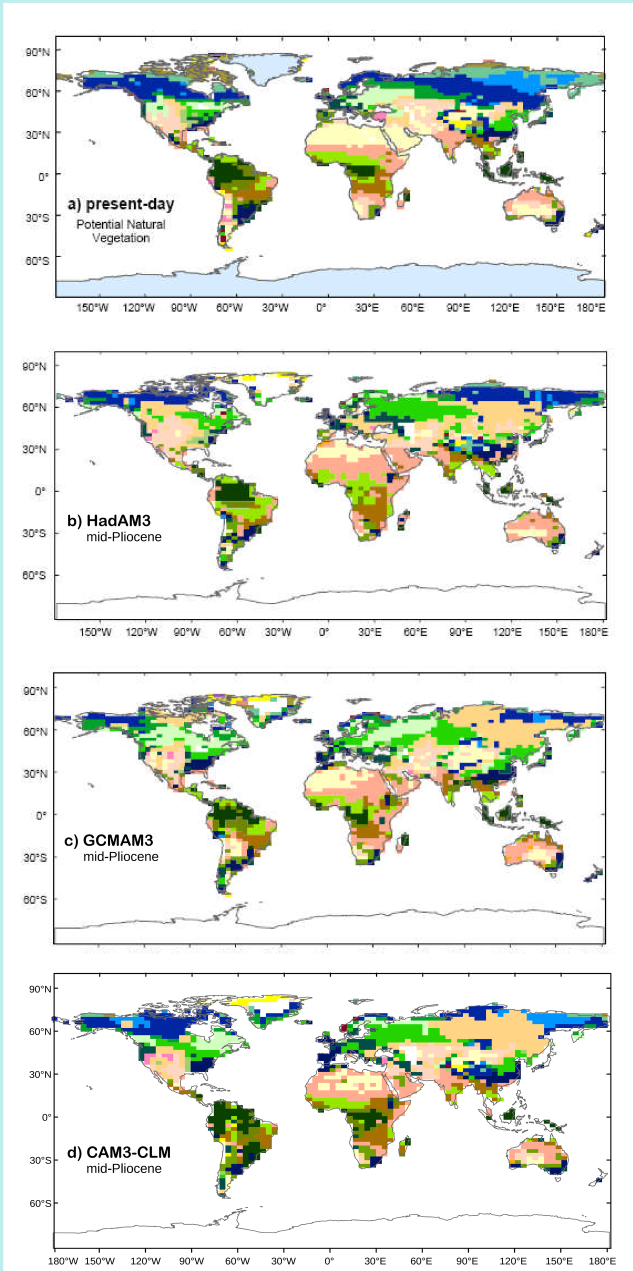


Figure 3: i) Piacenzian palaeobotanical sites and biomes used for the data-model comparisons (see Salzmann et al., 2008). Biomes were grouped in mega-biomes categories (in bold) modified after Harrison and Prentice (2003) ii) a) Present-day biomes simulated by BIOME 4 with present-day sea surface temperatures and a CO_2 concentration of 324 ppmv (Bonfils et al., 1998) and mid-Pliocene BIOME 4 simulations driven by b) HadAM3, c) GCMAM3 and d) CAM3-CLM.

Using the BIOME4 mechanistic model of vegetation (Kaplan, 2001), we obtained model-predicted biomes from all mid-Pliocene simulations which were then compared with a global reconstruction of biomes for the mid-Pliocene (Piacenzian Stage), derived from 202 localities (Salzmann et al., 2008). This was achieved using the ArcView3.x extension for Kappa statistics (Jenness and Wynne, 2005).

The Kappa Statistic measures the degree of agreement between predicted and observed categorisations of a dataset, providing a quantitative assessment of model skill whilst correcting for agreement that occurs by chance (Cohen, 1960). Kappa values between 0 and 1 are assigned a subjective label, where "0" means that the agreement is no better than would be expected by chance and "1" equates to a perfect match. To avoid the minimum number of sample points per category becoming too low for meaningful Kappa statistics, the 28 biomes were grouped into eight classes (after Harrison and Prentice, 2003).

Table 3: Kappa degree of agreement for mega-biomes (and biomes) produced by mid-Pliocene BIOME 4 simulations and between palaeobotanical data from 202 sites.

Region	HadAM3 vs. palaeobot data*	GCMAM3 vs. palaeobot data*	NCAR vs. palaeobot data*
GLOBAL	0.39 (0.30)	0.33 (0.25)	0.35 (0.25)
Polar & Boreal (>60 N)	0.39 (0.25)	0.23 (0.19)	0.30 (0.28)
Temperate (23,5 - 60° N/S)	0.30 (0.22)	0.22 (0.17)	0.25 (0.16)
Tropical (< 23,5 N/S)	0.26 (0.27)	0.38 (0.30)	0.26 (0.24)

5. Summary

Overall the models reproduce mean annual climatologies that are consistent in predicting the large scale changes in surface air temperatures and precipitation between the mid-Pliocene and present-day (Figure 1). The mid-Pliocene anomalies however, highlight significant differences between the models (Figure 2) including:

- Large differences between DJF surface air temperatures in the northern high latitudes, with HadAM3 up to 15 C warmer than GCMAM3 and over 15°C warmer than CAM3-CLM.
- Global mean DJF temperatures for HadAM3 over the majority of the continental regions are also higher than CAM3-CLM.
- JJA tropical and subtropical precipitation levels are significantly higher in HadAM3 compared with both GCMAM3 and CAM3-CLM, particularly over West Africa and the Indian Ocean, whilst over India the total precipitation rate is much reduced.
- Greater winter total cloud cover over the Arctic in HadAM3.