Supplementary Information for

Northward ITCZ shift drives reduced ENSO activity in the Mid-Pliocene Warm Period

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Contents of this file

Figures S1 to S8
Tables S1 to S2
Text S1

Introduction

This document provides additional information about the model output used in this study (Table S1) and PlioMIP1 and 2 boundary conditions (Text S1 and Table S2). Furthermore, we also provide additional information for the following analysis: (1) Change in the amplitude of SST variability in the PlioMIP1 models; (2) Separation of the Niño 3 amplitude change into interannual and decadal or lower periods; (3) Change in annual mean SST in the Tropical Pacific for each PlioMIP2 model; (4) Change in annual mean SST in the Tropical Pacific for each PLioMIP2 model; (5) Change in equatorial sub-surface temperature for PlioMIP1 models; (6) Evaluation of simulated ENSO non-linear characteristics for each PlioMIP2 model; (7) ENSO-ITCZ relationship for the models that accurately simulate ENSO non-linear characteristics; and (8) atmospheric circulation changes for PlioMIP1.

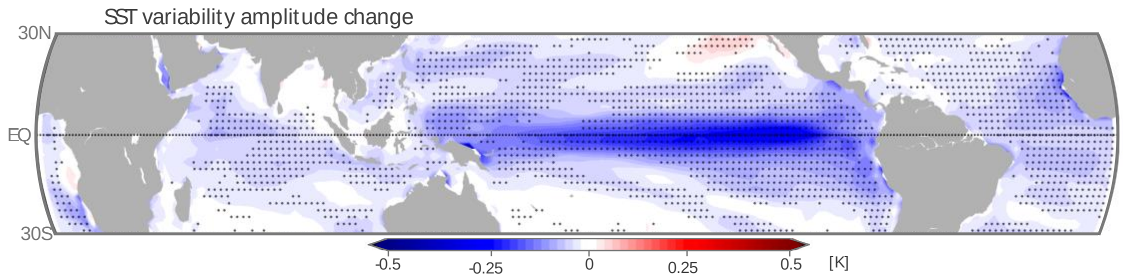

Figure S1 – Change in amplitude of SST anomalies in the PlioMIP1 models. Stippling indicates where the change is significant at the 95% level.

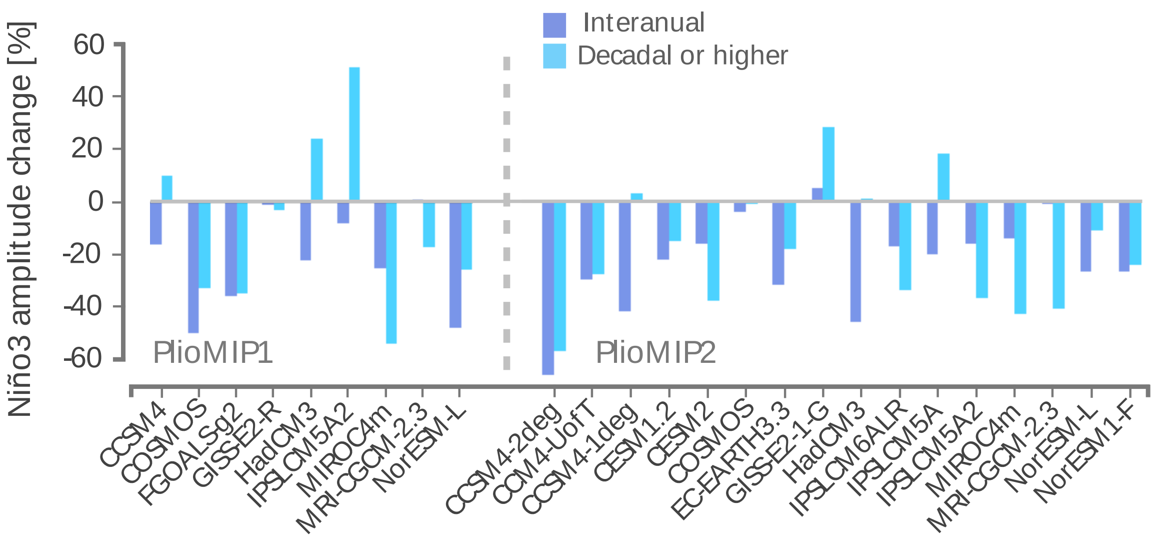

Figure S2 – mPWP changes in eastern Pacific SST variability by frequency bands. Percentage change in Niño3 (5ºN-5ºS; 150º-90ºW) standard deviation separated by interannual (dark blue) and decadal/multi-decadal (light blue) variability. The amplitude of decadal or higher periods is evaluated through the variance of the 11-year running mean Niño3 time series in each model. The amplitude of the interannual period is estimated as the variance of the residual time series, i.e. original Niño3 timeseries subtracted from the Niño3 decadal timeseries.

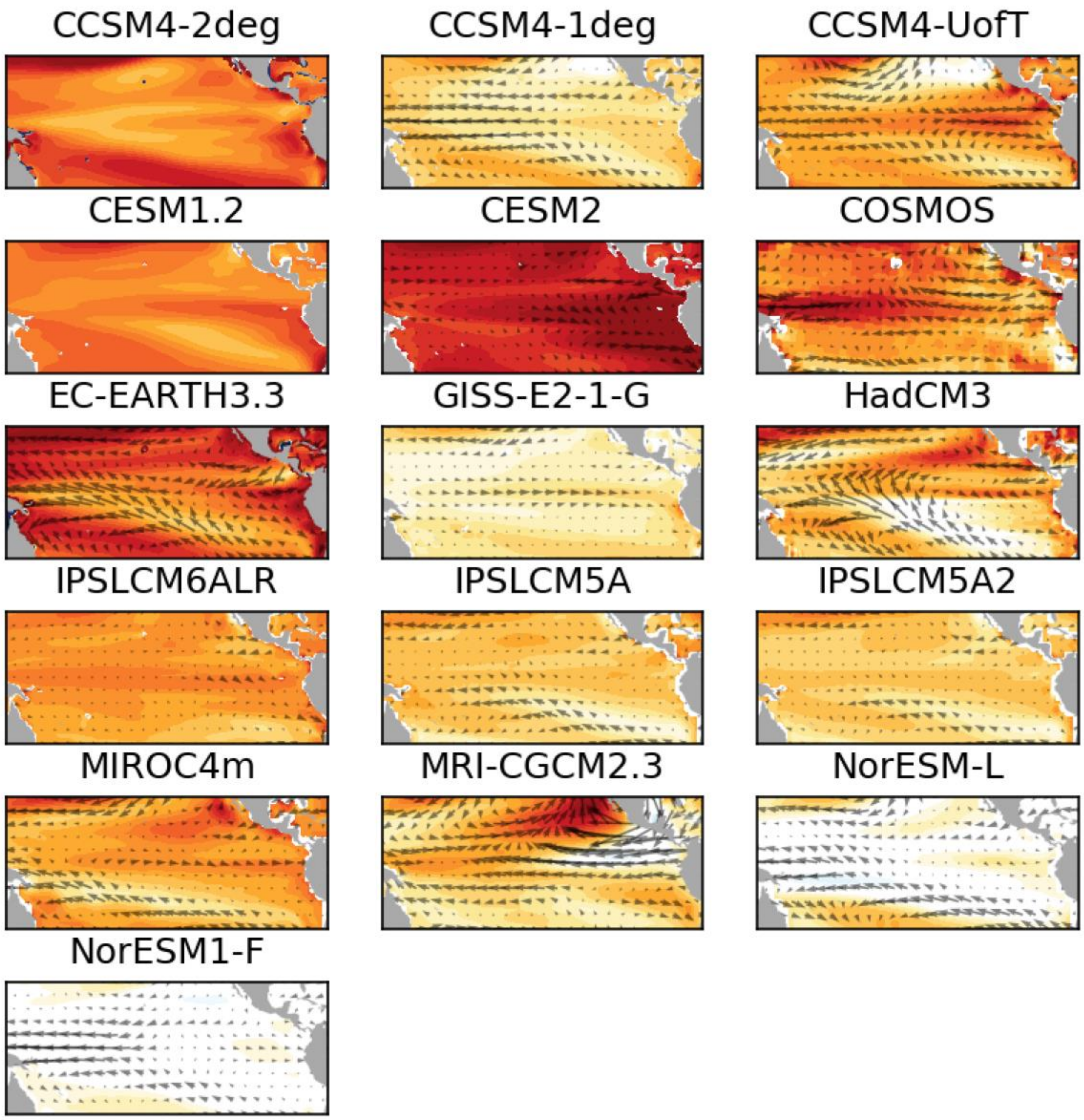

Figure S3 – Annual mean SST and low-level wind (850hPa) changes for the PlioMIP2 models.

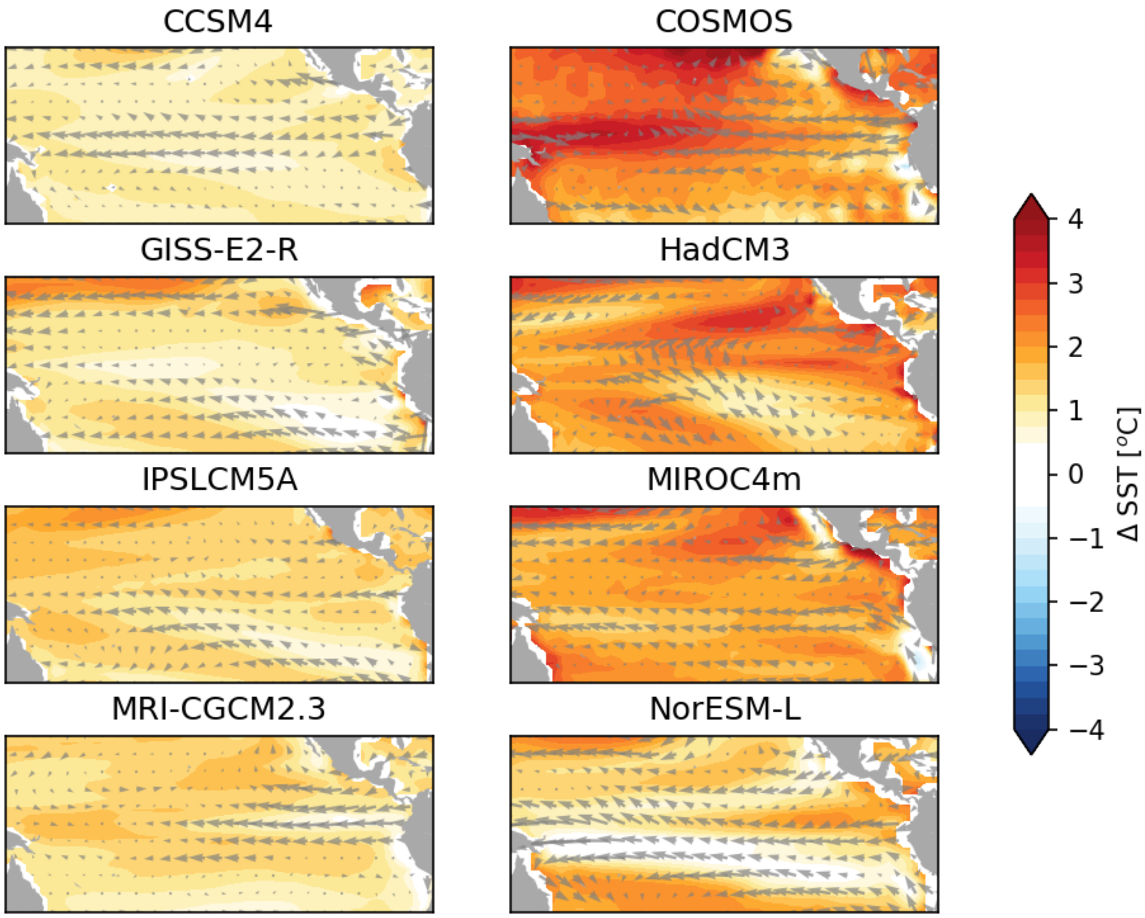

Figure S4 - As per figure 'S3' but for PlioMIP1 models.

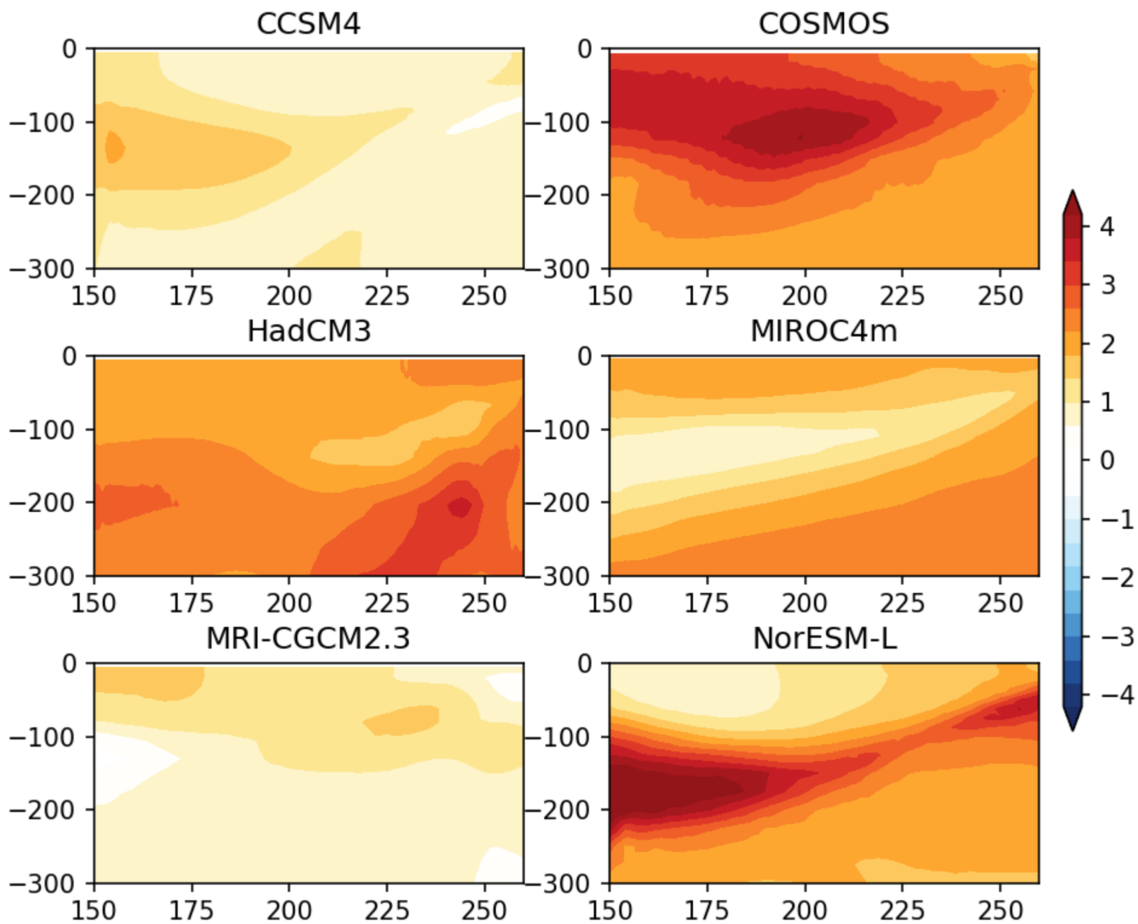

Figure S5 – Annual mean changes in sub-surface temperature for the PlioMIP1 models.

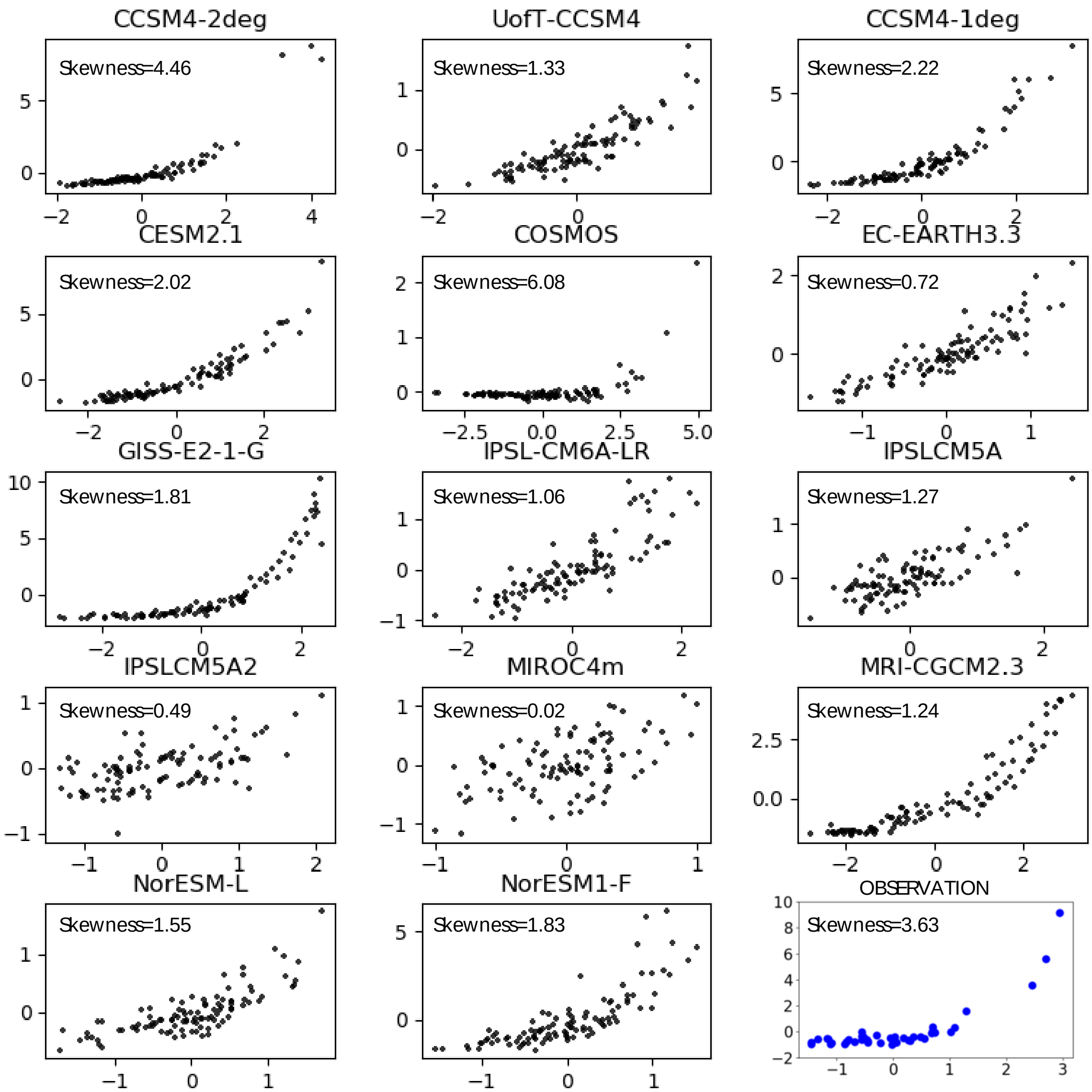

Figure S6 – ENSO non-linear characteristics for each PlioMIP2 models. Relationship between Niño3 SST anomalies (x-axis, ºC) and Niño3 rainfall anomalies (y-axis, mm/day) for the last 100 years of the pre-industrial control simulation of each model. Observed relationship was computed from GPCP and ERSSTv5 datasets from 1979 to 2020.

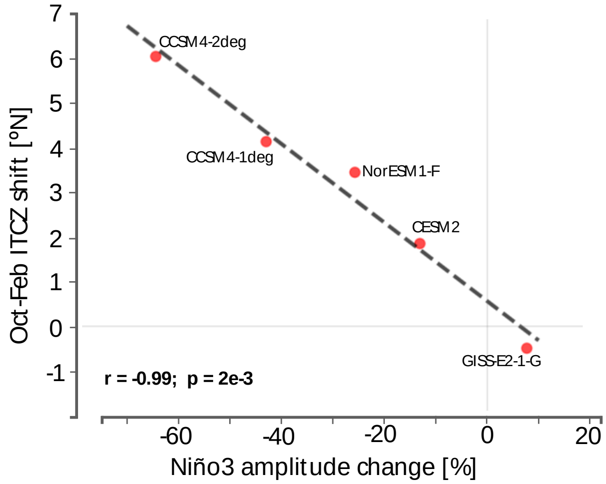

Figure S7 – Relationship between the change in the Niño3 amplitude and the mean October-to-February ITCZ shift for the models that correctly captured ENSO non-linear characteristics.

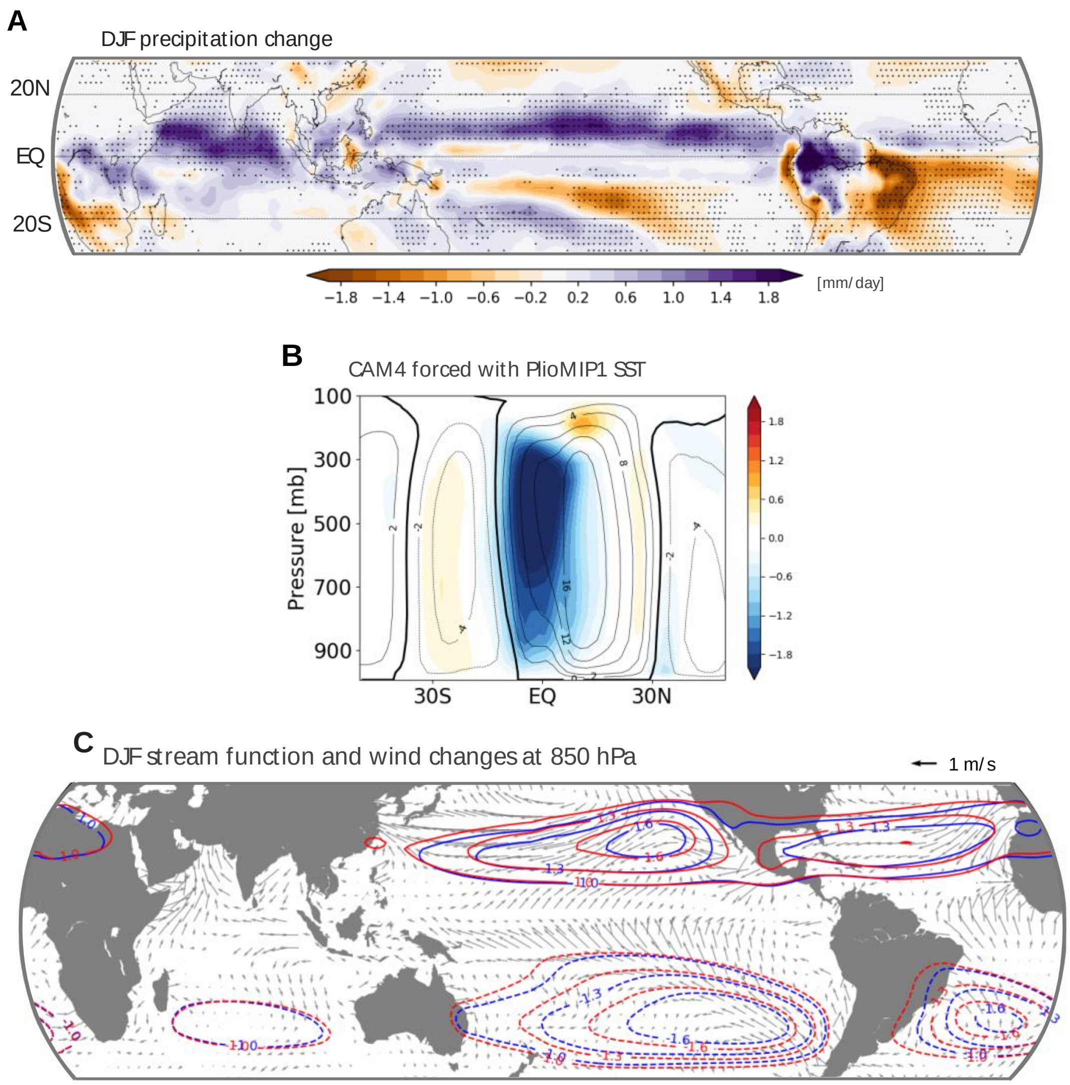

Figure S8 – Same results as show in main Figure 5 but for PlioMIP1 models. a) DJF precipitation change in the PlioMIP1 models (mid-Pliocene minus pre-industrial). Stippling indicates where the change is significant at the 95% level. b) Changes in the meridional streamfunction in the CAM4 experiment forced with PlioMIP1 SST and sea-ice (see Methods). c) Changes in global low-level (850 hPa) winds and streamfunction in the PlioMIP1 models. Wind changes are only plotted where there is a significant change at the 95% level.

Table S1. Models used in the present study.

	Institute	Ref.
PlioMIP1		
CCSM4	National Center for Atmospheric Research - USA	1
COSMOS	Alfred Wegener Institute – Germany	2
FGOALS-g2	LASG – China	3
GISS-E2-R	Goddard Institute for Space Studies – USA	4
HadCM3	University of Leeds – United Kingdom	5
IPSL-CM5A	Laboratoire des Sciences du Climat et de l'Environnement - France	6
MIROC4m	Centre for climate change research, Uni. Tokyo - Japan	7
MRI-CGCM2.3	University of Tsukuba – Japan	8
NorESM-L	Norwegian Research Centre – Norway	9
PlioMIP2		
CCSM4-UofT	University of Toronto – Canada	10,11
CCSM4-2deg	Utrecht University – The Netherlands	
CCSM4-1deg	National Center for Atmospheric Research – USA	12
CESM1.2	National Center for Atmospheric Research – USA	12
CESM2.1	National Center for Atmospheric Research – USA	12
COSMOS	Alfred Wegener Institute – Germany	13
EC-EARTH3.3	Stockholm University – Sweden	14
GISS-E2-1-G	Goddard institute for Space Studies – USA	
HadCM3	University of Leeds – United Kingdom	15
IPSL-CM6A-LR	Laboratoire des Sciences du Climat et de l'Environnement - France	16
IPSL-CM5A	Laboratoire des Sciences du Climat et de l'Environnement - France	17
IPSL-CM5A2	Laboratoire des Sciences du Climat et de l'Environnement - France	17
MIROC4m	Centre for climate change research, Uni. Tokyo - Japan	18
MRI-CGCM2.3	University of Tsukuba – Japan	19
NorESM-L	Norwegian Research Centre – Norway	20
NorESM1-F	Norwegian Research Centre – Norway	20

Table S2. PlioMIP1 and PlioMIP2 boundary conditions.

	LSM	Topo.	soils	lakes	Ice Greenl.	Ice Antarct.	vegetation	CO_2	Orbital Parameters
Pre-industrial	Modern	Modern	Modern	Modern	Modern	Modern	Modern	280	Modern
PlioMIP1 (experiment 2)	Plio	Plio	Modern	Modern	Plio (~50% retreat)	Plio	Plio	405	Modern
PlioMIP2 (Eoi400)	Plio – enhanced*	Plio – enhanced*	Plio	Plio	Plio (~70% retreat)	Plio	Plio	400	Modern

*MRI-CGCM2.3 was the only model that could not apply the enhanced reconstruction from PRISM4 and, thus, applied the previous, standard, reconstruction.

Text S1

PlioMIP phases 1 and 2 apply rather similar boundary conditions. Nonetheless there were significant differences at some regional locations, which can potentially affect large-scale climate[21-23]. First, although both phases have not applied changes in orbital parameters, phase 1 was designed to simulate a time averaged global SST reconstruction between 3 and 3.3 Ma BP, while phase focus in a narrower time slice (Marine Isotope Stage KM5c at 3.205 Ma BP) with almost identical orbital parameters to modern. Both phases applied a mPWP land-sea mask, but PlioMIP2 land-sea mask accounts for glacial isostatic adjustments and changes dynamic topography. This resulted in a subaerial Canadian Archipelago, Bering Strait and emergence of Sunda and Sahul shelves in the Indonesia and Australia region. Phase 2 models also applied soils and lakes reconstructions and a newer reconstruction of the Greenland ice sheet that now accounts for a 70% retreat, instead of the 50% retreat applied in phase 1. These reconstructions were derived from the U.S.

Geological Survey PRISM dataset, specifically the most recent and fourth version iteration of the reconstructions (PRISM4)[24]. In PlioMIP2, modelling groups could choose from either using the vegetation reconstruction from Salzmann et al. (2008), same as PlioMIP1, or use dynamic model vegetation option. COSMOS was the only model among PlioMIP2 participants to use dynamic vegetation. For a detailed description of each model's implementation, please see references in Table S1.

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