Quaternary Science Reviews 82 (2013) 104–120

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Mid-Holocene net precipitation changes over China: model–data comparison

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A R T I C L E I N F O

Article history:
Received 18 December 2012
Received in revised form
15 October 2013
Accepted 16 October 2013
Available online 9 November 2013

Keywords:
Mid-Holocene
Net precipitation
Model–data comparison
Climate model
China

A B S T R A C T

Many efforts have been made to reconstruct the moisture conditions over China during the mid-Holocene, approximately 6000 calendar years ago. However, most of them have been performed at the single site level or local scale, and the nationwide distribution of the mid-Holocene precipitation and net precipitation (precipitation minus evaporation) changes from both proxy data and simulations remains unclear. Here we first selected 36 out of 51 climate models participating in the Paleoclimate Modeling Intercomparison Project (PMIP) for their demonstrable ability to simulate the baseline climate and for the availability of evaporation data. Our analysis of the ensemble mean results of the 36 models shows that the mid-Holocene annual precipitation, evaporation, and net precipitation were 3.0%, 0.9%, and 6.9% more than the baseline period, respectively, and seasonally all three variables decreased in boreal winter and spring but increased in boreal summer and autumn on the national scale. For that period, both the pattern and magnitude of the above changes differed between the models and the sub-regions, and the interactive ocean effect had little impact overall on the country. Compared with the wetter-than-present climates derived from the records at 64 out of 69 sites across China, the models agreed qualitatively with the multi-proxy data in most parts of China, except Xinjiang and the areas between the middle and lower reaches of the Yangtze and Yellow River valleys, where drier-than-baseline climates were obtained from the 36 models.

1. Introduction

Short instrumental records hamper our knowledge of climate change on decadal and longer timescales. Insights into the facts and mechanisms of past climate and environmental changes are thus essential for better understanding present and future climates. The mid-Holocene is a well-known period approximately 6000 years before present when the climate and environment differed from the present day, and it provides an excellent opportunity to examine how the climate system responds to changes in the latitudinal and seasonal distribution of insolation due to orbital forcing. In recent decades, considerable effort has been dedicated to the synthesis of proxy data and simulations as well as model–data comparisons for the mid-Holocene worldwide (e.g., Joussaume and Taylor, 1995; Guiot et al., 1999; Tarasov et al., 1999; Masson-Delmotte et al., 2006; Peyron et al., 2006; Braconnot et al., 2007; Zhang et al., 2010). It has been found that climate models are able to reproduce many of the robust qualitative large-scale features of reconstructed climate change, consistent with the understanding of orbital forcing (Jansen et al., 2007). On the regional scale, however, simulations have been found to be opposite the reconstructions of annual and winter (December–January–February) temperature changes in China (Jiang et al., 2012). An unresolved question at this stage is how the mid-Holocene moisture conditions are derived from both climate models and single-site-based proxy data over the country.

Using individual climate models of different complexities, several numerical experiments have been undertaken to address the mid-Holocene climate over China (Wang, 1999, 2000, 2002; Chen et al., 2002; Wei and Wang, 2004; Zheng et al., 2004; Zheng

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0277-3791/$ – see front matter
http://dx.doi.org/10.1016/j.quascirev.2013.10.017

Table 1
Basic information on the general circulation models used in the present study.

Model ID		Project	Atmospheric resolution	Length of run analyzed (year)	Baseline period
01	CCC2.0	PMIP1 (AGCM)	T32L10	10	Modern
02	CCM3	PMIP1 (AGCM)	T42L18	8	Modern
03	CCSR1	PMIP1 (AGCM)	T21L20	10	Modern
04	CNRM-2	PMIP1 (AGCM)	T31L19	10	Modern
05	CSIRO	PMIP1 (AGCM)	R21L9	15	Modern
06	ECHAM3	PMIP1 (AGCM)	T42L19	10	Modern
07	GEN2	PMIP1 (AGCM)	T31L18	10	Modern
08	GFDL	PMIP1 (AGCM)	R30L20	25	Modern
09	GISS-IIP	PMIP1 (AGCM)	72 × 46, L9	10	Modern
10	LMCELMD4	PMIP1 (AGCM)	48 × 36, L11	15	Modern
11	LMCELMD5	PMIP1 (AGCM)	64 × 50, L11	15	Modern
12	MRI2	PMIP1 (AGCM)	72 × 46, L15	10	Modern
13	UGAMP	PMIP1 (AGCM)	T42L19	20	Modern
14	UIUC11	PMIP1 (AGCM)	72 × 46, L14	10	Modern
15	UKMO	PMIP1 (AGCM)	96 × 73, L19	50	Modern
16	YONU	PMIP1 (AGCM)	72 × 46, L7	10	Modern
17	CCSM3.0	PMIP2 (AOGCM)	T42L18	50	Pre-industrial
18	CSIRO-Mk3L-1.0	PMIP2 (AOGCM)	R21L18	1000	Pre-industrial
19	CSIRO-Mk3L-1.1	PMIP2 (AOGCM)	R21L18	1000	Pre-industrial
20	ECBILTCLIOVECODE	PMIP2 (AOGCM)	T21L3	100	Pre-industrial
21	ECHAME5-MPIOM1	PMIP2 (AOGCM)	T31L20	100	Pre-industrial
22	ECHAM53-MPIOM127-LPJ	PMIP2 (AOGCM)	T31L19	100	Pre-industrial
23	FGOALS-1.0 g	PMIP2 (AOGCM)	R42L9	100	Pre-industrial
24	FOAM	PMIP2 (AOGCM)	R15L18	100	Pre-industrial
25	GISSmodelE	PMIP2 (AOGCM)	72 × 46, L17	50	Pre-industrial
26	IPSL-CM4-V1-MR	PMIP2 (AOGCM)	96 × 72, L19	100	Pre-industrial
27	MIROC3.2	PMIP2 (AOGCM)	T42L20	100	Pre-industrial
28	MRI-CGCM2.3.4fa	PMIP2 (AOGCM)	T42L30	150	Pre-industrial
29	MRI-CGCM2.3.4nfa	PMIP2 (AOGCM)	T42L30	150	Pre-industrial
30	UBRIS-HadCM3M2	PMIP2 (AOGCM)	96 × 73, L19	100	Pre-industrial
31	ECBILTCLIOVECODE-veg	PMIP2 (AOVGCM)	T21L3	100	Pre-industrial
32	ECHAM53-MPIOM127-LPJ-veg	PMIP2 (AOVGCM)	T31L19	100	Pre-industrial
33	FOAM-veg	PMIP2 (AOVGCM)	R15L18	100	Pre-industrial
34	MRI-CGCM2.3.4fa-veg	PMIP2 (AOVGCM)	T42L30	100	Pre-industrial
35	MRI-CGCM2.3.4nfa-veg	PMIP2 (AOVGCM)	T42L30	100	Pre-industrial
36	UBRIS-HadCM3M2-veg	PMIP2 (AOVGCM)	96 × 73, L19	100	Pre-industrial
37	BCC-CSM1.1	PMIP3 (AOVGCM)	T42L26	100	Pre-industrial
38	CCSM4	PMIP3 (AOGCM)	288 × 192, L26	301	Pre-industrial
39	CNRM-CM5	PMIP3 (AOGCM)	256 × 128, L31	200	Pre-industrial
40	CSIRO-Mk3-6-0	PMIP3 (AOGCM)	192 × 96, L18	100	Pre-industrial
41	CSIRO-Mk3L-1-2	PMIP3 (AOGCM)	64 × 56, L18	500	Pre-industrial
42	EC-EARTH-2-2	PMIP3 (AOGCM)	320 × 160, L62	40	Pre-industrial
43	FGOALS-g2	PMIP3 (AOVGCM)	128 × 60, L26	100	Pre-industrial
44	FGOALS-s2	PMIP3 (AOVGCM)	128 × 108, L26	100	Pre-industrial
45	GISS-E2-R	PMIP3 (AOGCM)	144 × 90, L40	100	Pre-industrial
46	HadGEM2-CC	PMIP3 (AOVGCM)	192 × 145, L60	35	Pre-industrial
47	HadGEM2-ES	PMIP3 (AOVGCM)	192 × 145, L38	102	Pre-industrial
48	IPSL-CM5A-LR	PMIP3 (AOVGCM)	96 × 95, L39	500	Pre-industrial
49	MIROC-ESM	PMIP3 (AOVGCM)	T42L80	100	Pre-industrial
50	MPI-ESM-P	PMIP3 (AOGCM)	T63L47	100	Pre-industrial
51	MRI-CGCM3	PMIP3 (AOGCM)	320 × 160, L48	100	Pre-industrial

and Yu, 2009; Zhou and Zhao, 2010; Liu et al., 2010a). They have well explained the increase of surface temperature and the intensification of monsoon, as suggested by proxy data, over China during the mid-Holocene summer (June–July–August). At the same time, these experiments have shown a large inter-model spread in the magnitude and sign of the mid-Holocene precipitation changes. Among these simulations, for example, the mid-Holocene summer precipitation increased consistently over eastern China (Wang, 1999), while it increased in southern and northeastern China but decreased in central and northern China (Zheng and Yu, 2009). For that period, the annual precipitation increased over western China, northern China, and most parts of southern China, but decreased in the middle and lower reaches of the Yangtze River valley and coastal southern China (Zheng et al., 2004), while large orbital-induced variations of annual precipitation occurred only in northeastern China (Liu et al., 2010a). Such model-dependent uncertainties make it of particular interest to integrate the outputs of multiple climate models to analyze the similarities and differences between the model results of precipitation. Next, dynamic ocean and vegetation are two key components of the climate system, and their effects have been identified as important for the mid-Holocene climate (e.g., Kutzbach et al., 1996; Ganopolski et al., 1998; Zhao et al., 2005; Braconnot et al., 2007; Jansen et al., 2007; Dallmeyer et al., 2010). However, these components have not or have only been partly taken into account in the aforementioned experiments with atmospheric general circulation models (AGCMs) (Wang, 1999, 2000, 2002; Chen et al., 2002), regional climate models nested within AGCMs (Zheng et al., 2004; Liu et al., 2010a), an asynchronously coupled atmosphere–ocean general circulation model (Wei and Wang, 2004), and fully coupled