

Summer Extreme Temperatures over East China during 1984–2004 Simulated by LASG/IAP Regional Climate Model CREM

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Abstract The authors examine extreme summer temperatures over East China during 1984–2004 using a regional climate model named CREM (the Climate version of Regional Eta-coordinate Model), which was developed by LASG/IAP. The results show that the main features of the extreme summer temperatures over East China are reproduced well by CREM, and the skill for the minimum temperature is higher than that for the maximum temperature, especially along the Yangtze-Huai River Valley (YHV). The simulated extreme temperatures are lower than those of observation, especially for the maximum temperature. The bias of extreme temperatures is consistent with the cold bias of the climatological mean summer surface air temperature. The skill of the model in simulating the interannual variability of extreme temperatures increases from north to south. The simulated interannual variation of the minimum temperature is more reasonable than the maximum temperature. The underestimation of net solar radiation at the surface leads to a cold bias of the climatological mean temperature. Furthermore, the model underestimates the light and moderate rain, while overestimates heavy rain. It causes the simulated minimum temperature more reasonable than the maximum temperature.

Keywords: summer extreme temperatures, East China, CREM

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1 Introduction

The global mean surface air temperature (SAT) has increased by 0.74°C during the period of 1906–2005 (Intergovernmental Panel on Climate Change (IPCC), 2007). As in many other parts of the world, regional warming trends are evident in China (Yan et al., 2002; Liu et al., 2006; Fu et al., 2008). There is greater concern over the changes of extreme temperatures than mean temperature due to their larger impact on society (Li et al., 2011). Observational analysis indicates that the warming trend of the minimum temperature (T_{\min}) is stronger than the maximum temperature (T_{\max}) in many parts of the world

(Zhai and Pan, 2003; Alexander et al., 2006).

Numerical models are useful tools in climate change studies. However, global coupled models generally show bias in simulating the regional features of SAT changes over China (Zhou and Yu, 2006). Many global models exhibit cold biases, especially in western China (Li et al., 2011). The simulated summertime T_{\min} over China was found to be more reasonable than T_{\max} (Wang et al., 2008; Li et al., 2011).

In comparison with relatively low resolution global models, regional climate models (RCMs) can provide fine resolution features when forced by coarse resolution datasets derived from either global models or reanalysis datasets. It is easy to set various physical parameterizations over different regions for RCMs, while GCMs can only utilize uniform ones (Giorgi and Mearns, 1999; Leung et al., 2004; Wang et al., 2004; Giorgi et al., 2009). Furthermore, RCMs have been widely used in dynamically downscaling regional extreme temperature changes (Koo and Hong, 2010; Gao et al., 2001, 2002).

In recent years, efforts have been devoted to the development of a Climate version of the Regional Eta-coordinate Model (CREM) at the State Key Laboratory of Numerical Modeling for Atmospheric Science and Geophysical Fluid Dynamics/Institute of Atmospheric Physics (LASG/IAP). The model has shown reasonable performance in simulating the spatial distributions of summer climatological mean precipitation and circulation (Shi et al., 2009), the rainfall pattern during an ENSO-decaying summer (Zeng et al., 2011), the intraseasonal oscillation of summer rainfall over East China (Zhao et al., 2011), and extreme precipitation (Liu et al., 2012). However, the performance of the model in dynamically downscaling regional extreme temperature over China is unknown. The main motivation of the current paper is to assess the performance of CREM in reproducing both the climate mean pattern and the interannual variability of extreme temperature over East China.

The remainder of the paper is organized as follows: a brief introduction of the experiment design is given in Section 2; the results are detailed in Section 3; and Section 4 presents a summary.

2 Experiment design

The model description has been detailed in previous

works (Shi et al., 2009; Zeng et al., 2011). The integration domain used in this study covers 13–53°N, 90–140°E, which is the same as Liu et al. (2012). The American National Centers for Environmental Prediction-Department of Energy (NCEP-DOE) Reanalysis (hereafter, NCEP2) data, at 2.5°×2.5° and four times per day (Kanamitsu et al., 2002), are used as the initial and lateral boundary conditions for CREM. The SST forcing data are from the weekly Optimally Interpolated Sea Surface Temperature (OISST) data with a resolution of 1°×1° (Reynolds et al., 2002). For each summer during the period of 1984–2004, the model is integrated from April to August, and the daily temperature datasets from Jun to August are used for the analysis.

The validation datasets include the following: (1) the observational temperature datasets on a 0.5°×0.5° grid (Xu et al., 2009) and (2) the International Satellite Cloud Climatology Project (ISCCP) monthly radiation datasets on a 2.5°×2.5° grid (Zhang et al., 2004). The period of the observational datasets is also 1984–2004.

3 Results

3.1 Climatological mean

The distribution of the climatological June–August (JJA) mean temperature is shown in Fig. 1. In summer, the warm center is located over East China, south of 40°N and east of 105°E (Fig. 1a). The main spatial distribution of SAT in the observational data can be reproduced by CREM (Fig. 1b). However, there are two cold bias bands that contrast with the observational data. The most obvious cold bias band, approximately -3°C in magnitude, is over northern China, while the weaker one, approximately -1.5°C in magnitude, south of the Yangtze River Valley (Fig. 1c).

Following Gong and Han (2004), we define that T_{\min} is represented by the 10th percentile and T_{\max} by the 90th percentile of daily temperature in ascending order. The spatial distributions of T_{\min} and T_{\max} are shown in Fig. 2. The observed distributions of the extreme temperatures are similar to that of the climatological SAT (Figs. 2a and 2b). The low-value center over the Tibet Plateau and the high-value center over the Yangtze-Huai River Valley (YHV) can also be captured by the model (Figs. 2c and 2d). The distribution feature of T_{\min} over the south of 32°N is also well simulated, except for a slight warm bias (Fig. 2e). The main discrepancy is the cold bias band over the north of 37°N for the extreme temperatures (Figs. 2e and 2f), corresponding to the cold bias band in the climatological mean temperature (Fig. 1c). A slight cold bias band can also be found over the south of 32°N for T_{\max} (Fig. 2f). Generally speaking, T_{\min} is more reasonably simulated than T_{\max} .

East China is not a uniform monsoon region, and the local climate characteristics are dominant over various regions. Figure 3 shows the probability density functions (PDFs) of the climatological mean summer daily temperatures over the three regions of East China: North

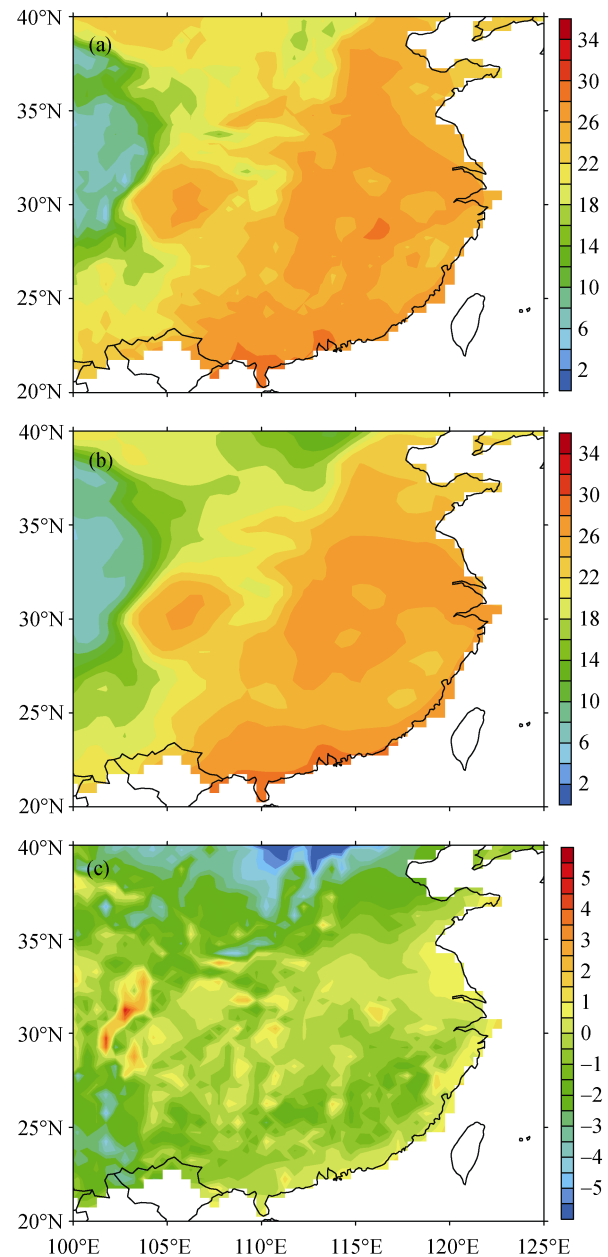


Figure 1 Climatological mean temperature and model bias in JJA during the period of 1984–2004: (a) observation, (b) model, and (c) the bias; units: $^{\circ}\text{C}$.

China (NC, 34–40°N, 105–122°E), YHV (26–34°N, 105–122°E) and South China (SC, 20–26°N, 105–122°E) in the observational data and the model simulation for the period of 1984–2004. It can be seen that the dominant temperature is the highest in SC, and it decreases from south to north. The main features are well captured by the model. Among these three regions, the simulated PDF is the most consistent with the observational data over YHV (Fig. 3b). The PDFs of low temperature over NC and SC are slightly overestimated, while the PDFs of high temperature are underestimated (Figs. 3a and 3c).

The skill scores of the extreme temperatures simulated by CREM over different parts of East China are also analyzed (Table 1). From the table, the skill scores over YHV are higher than over the other regions. In contrast to the

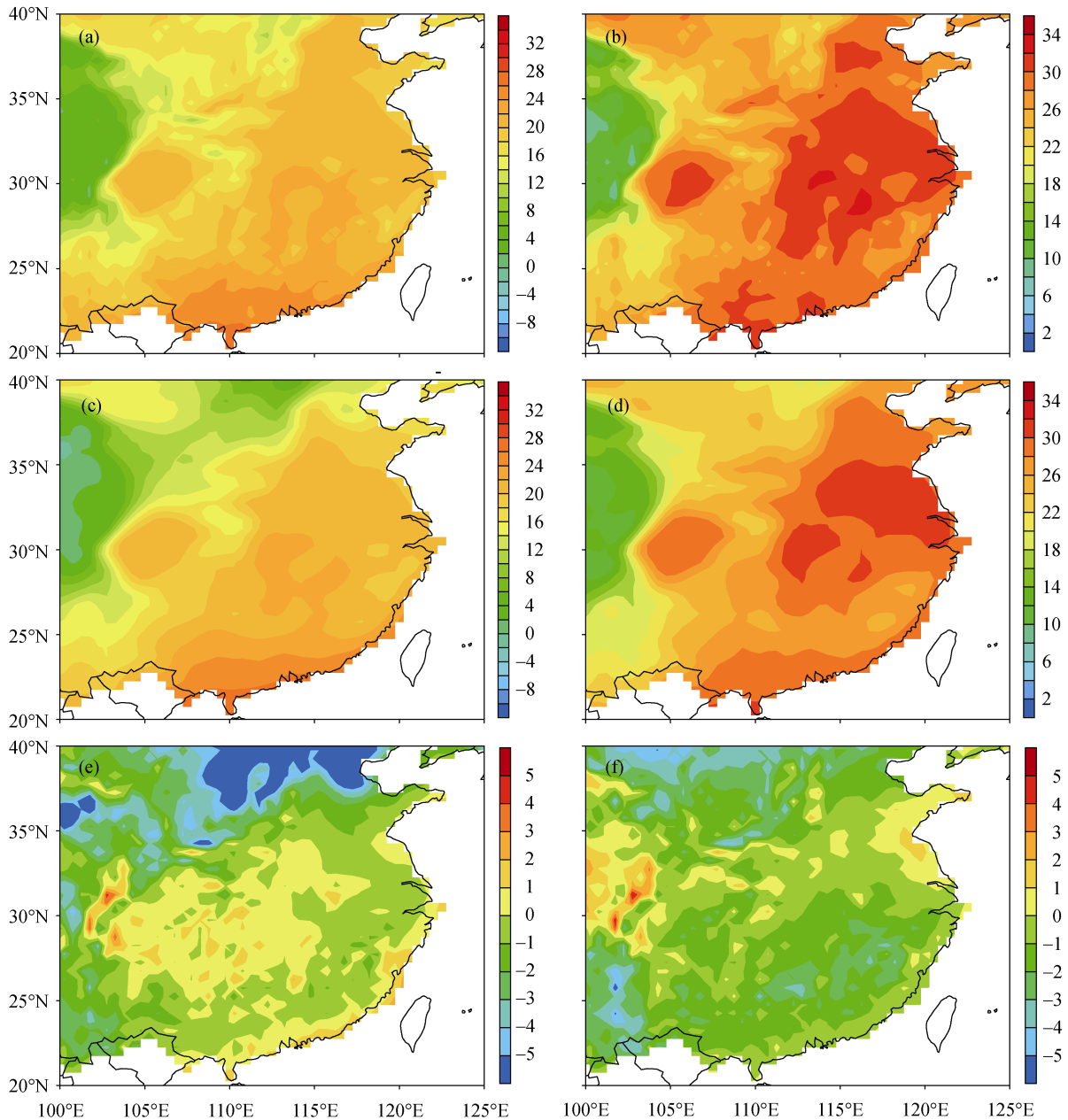


Figure 2 The spatial distribution of JJA mean T_{\min} (1984–2004) (10%) (the left column) and T_{\max} (1984–2004) (90%) (the right column) in the observational data (the top panel), model simulation (the middle panel), and model bias (the bottom panel); units: $^{\circ}\text{C}$.

observational data, the correlation coefficients are 0.818, 0.922, and 0.918 for the simulated T_{\min} and 0.908, 0.931, and 0.871 for the simulated T_{\max} over NC, YHV, and SC, respectively. The Root mean square errors (RMS) are 3.925, 0.846, and 0.883 for T_{\min} and 1.933, 1.270, and 1.439 for T_{\max} over NC, YHV, and SC between the model and the observational data, respectively. From the correlation coefficient comparison, the simulated T_{\min} and T_{\max} are close to one another, while the RMS comparison indicates that the simulated T_{\min} is more reasonable than the T_{\max} , except over NC.

3.2 Interannual variations of the extreme temperatures

The interannual variations of summer extreme tem-

peratures over three regions of East China are assessed in Fig. 4. These variations are well simulated by the model. The correlation coefficients are 0.64, 0.67, and 0.93 for T_{\min} and 0.78, 0.61, and 0.89 for T_{\max} over NC, YHV, and SC between the model and the observational data, respectively. The ratios of the standard deviations are 0.96, 1.19, and 0.84 for T_{\min} and 1.00, 1.15, and 0.96 for T_{\max} between CREM and the observational data, respectively. The ability of the model to simulate the interannual variability increases from north to south. Among these three regions, the amplitudes of the interannual variation over YHV are greater than in the observational data, while those over the other two regions are less than in the observational data. Generally, the simulated interannual variation of T_{\min} is more accurate than T_{\max} .

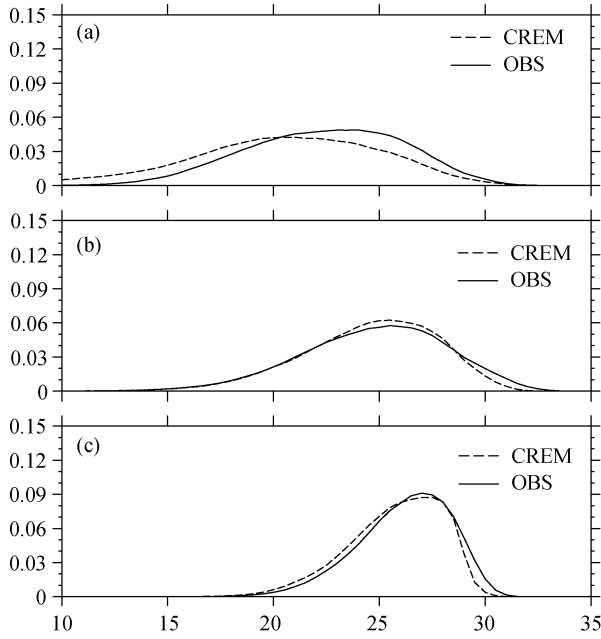


Figure 3 Probability distribution functions of JJA daily SAT over (a) NC (34–40°N, 105–122°E), (b) YHV (26–34°N, 105–122°E), and (c) SC (20–26°N, 105–122°E); units: °C.

Table 1 Spatial correlation coefficients (SCC) and RMS between the simulation and the observation data of the extreme temperatures over three regions: NC (34–40°N, 105–122°E), YHV (26–34°N, 105–122°E), and SC (20–26°N, 105–122°E).

Region	SCC		RMS	
	T_{min}	T_{max}	T_{min}	T_{max}
NC	0.818	0.908	3.925	1.933
YHV	0.922	0.931	0.846	1.270
SC	0.918	0.871	0.883	1.439

3.3 Discussion

The main discrepancies of the simulated extreme temperatures over East China are cold biases, which are consistent with the cold biases of the climatological mean temperature (Fig. 1c).

The surface of the Earth is mainly heated by solar radiation. The JJA mean net solar radiations of the simulation, the observational data, and the bias at the surface for the period of 1984–2004 are shown in Fig. 5. The simulated net shortwave flux at the land surface has a much lower bias, approximately -80 W m^{-2} in magnitude, than in the observational data, which may be the reason for the cold bias of the climatological mean summer SAT.

What causes the lower bias of the net shortwave flux at the surface? The summer shortwave cloud radiation cooling effect in CREM is stronger than in the observational data, and the amount of clear sky shortwave net flux at the top of the atmosphere is lower than in the observation data (Wu, 2010). Meanwhile, the BATS1e (Biosphere-Atmosphere Transfer Scheme 1e) scheme used in CREM simulates more latent heat flux and less sensible heat flux (Lee and Suh, 2000; Winter et al., 2009; Shi et al., 2009). All of these factors result in much weaker heating at the surface in the model than in the observational data.

The light and moderate precipitation is underestimated by the model, while the heavy rain is overestimated (Liu et al., 2012). The heavy rain has a greater cooling effect on SAT. It maybe causes the model to present a warmer T_{min} and cooler T_{max} against the observation data. This result also explains why the simulated T_{min} is more accurate than the T_{max} .

4 Summary

This study assessed the performance of the LASG/IAP

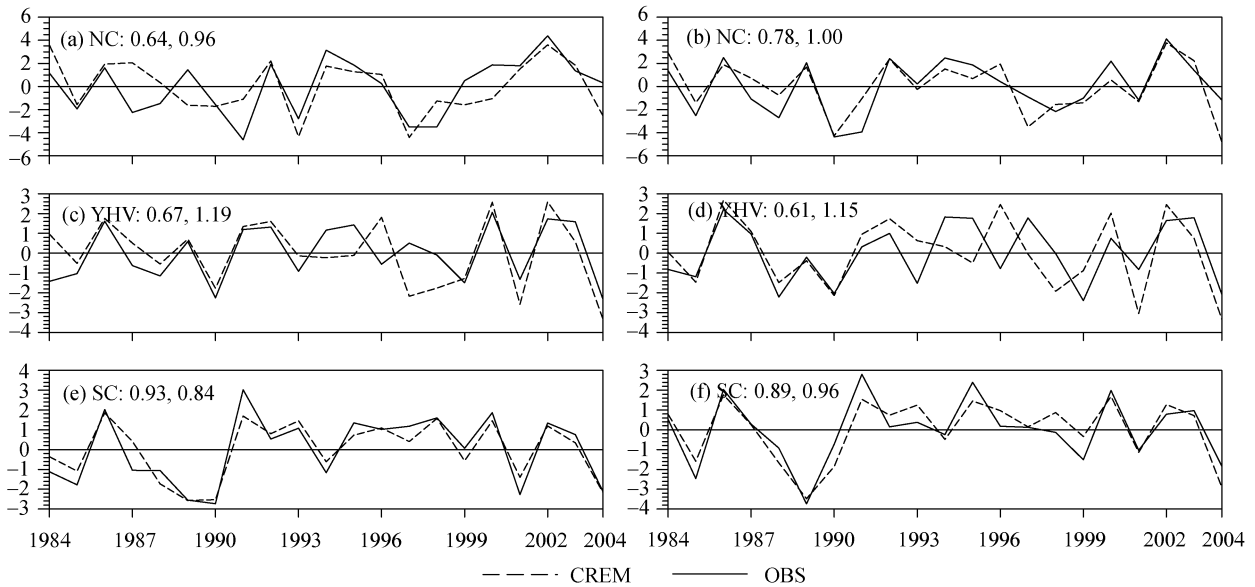


Figure 4 The interannual variation of extreme temperatures over (a, b) NC, (c, d) YHV, and (e, f) SC for T_{min} (left column) and T_{max} (right column), respectively; units: °C. The first and second values at the top of each figure denote the correlation coefficient and the ratios of standard deviations, respectively, between the model simulations.

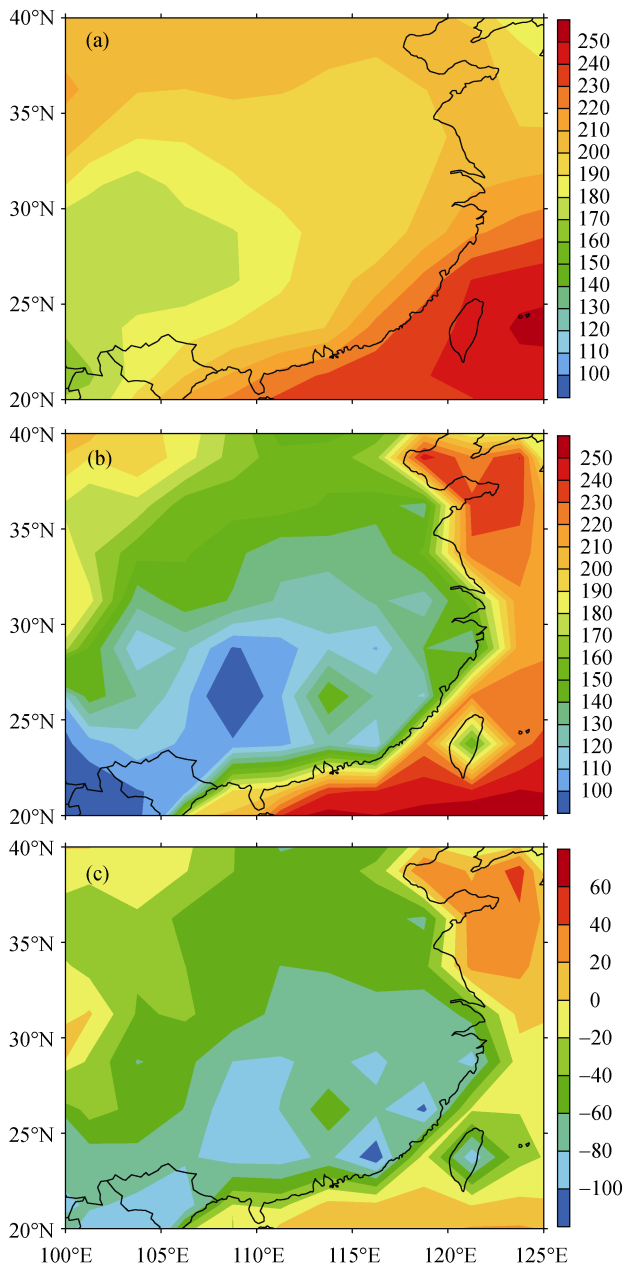


Figure 5 The JJA mean net solar radiation in (a) the observational data, (b) the simulation, and (c) the model bias at the surface for the period 1984–2004; units: W m^{-2} .

regional climate model CREM in simulating the extreme temperature over eastern China. The main findings are summarized as follows:

(1) The main features of the summer extreme temperatures over East China are reasonably reproduced by the model. The simulated minimum temperature is more reasonable than the maximum temperature, especially along the Yangtze-Huai River Valley.

(2) The simulated summer extreme temperatures exhibit cold biases, especially for the maximum temperature, consistent with the cold biases of the climatological mean summer surface air temperature.

(3) The ability of the model to simulate the interannual variability of extreme temperature increases from north to

south. The interannual variation of the minimum temperature is more reasonably simulated than the maximum temperature.

(4) The cold biases of the climatological mean summer temperature resulted from the underestimation of net solar radiation at the surface. Furthermore, the model underestimates and overestimates light and moderate rain and heavy rain, causing the simulated minimum temperature to be more accurate than the maximum temperature.

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