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The Extreme Summer Precipitation over East China during 1982–2007 Simulated by the LASG/IAP Regional Climate Model

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Abstract The extreme summer precipitation over East China during 1982–2007 was simulated using the LASG/IAP regional climate model CREM (the Climate version of a Regional Eta-coordinate Model). The results show that the probability density functions (PDFs) of precipitation intensities are reasonably simulated, except that the PDFs of light and moderate rain are underestimated and that the PDFs of heavy rain are overestimated. The extreme precipitation amount (R95p) and the percent contribution of extreme precipitation to the total precipitation (R95pt) are also reasonably reproduced by the CREM. However, the R95p and R95pt over most of East China are generally overestimated, while the R95p along the coastal area of South China (SC) is underestimated. The bias of R95pt is consistent with the bias of precipitation intensity on wet days (SDII). The interannual variation for R95p anomalies (PC1) is well simulated, but that of R95pt anomalies (PC2) is poorly simulated. The skill of the model in simulating PC1 (PC2) increases (decreases) from north to south. The bias of water vapor transport associated with the 95th percentile of summer daily precipitation (WVTr95) explains well the bias of the simulated extreme precipitation.

Keywords: regional climate simulation, extreme precipitation, East China, CREM

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1 Introduction

East China is characterized by its exceptionally complex topography, varied ecological landscapes, and typical monsoon climate. Extreme precipitation events, which are the major cause of severe floods in East China, mainly occur in the summer. These events greatly affect populations and the environment and frequently result in the substantial loss of lives and damage to the economy (Feng et al., 2007). Previous studies indicate that extreme precipitation events are sensitive to climate change (Easterling et al., 2000) and that they may increase in the future (Intergovernmental Panel on Climate Change (IPCC), 2007; Feng et al., 2011; Li et al., 2011). The increasing extreme precipitation events can lead to more flood catastrophes and can have significant impacts on society and the economy (Yu and Zhou, 2007; Zhou et al., 2008, 2009a).

Climate models are useful tools in climate change and variability studies (Zhou et al., 2007). It is essential to evaluate the performance of the models in simulating extreme precipitation. Global climate models (GCMs) often perform poorly in simulating regional climate and its change, especially over regions with complex terrain and coastlines, due to their insufficient horizontal resolutions, which are unable to accurately describe the physical processes of the atmosphere and land surfaces (Zhou and Li, 2002; Zhou and Yu, 2006; Zhou et al., 2008, 2009b; Li et al., 2010; Chen et al., 2010). To overcome the limitation of global climate models, regional climate models (RCMs) have been developed since the end of the 1980s (Dickinson et al., 1989; Giorgi, 1990). RCMs have been widely used in climate simulations for various regions and climate regimes (Leung et al., 2003; Wang et al., 2004). However, RCMs are sensitive to physical processes (Hu et al., 2008), spin-up time (Zhong et al., 2007), buffer zone size (Zhong et al., 2010), and lateral boundary conditions (Wang and Yang, 2008). Although RCMs still show biases in mountainous regions and during the summer season, it has been demonstrated that RCMs can generally produce credible processes of regional-scale energy and hydrological cycles (Giorgi et al., 1993a, b).

The diurnal variation of temperature can be well simulated by RCMs as soil, canopy and topography are well treated in RCMs (Zhang and Qian, 1995). Using a regional model (RegCM3) nested within a general circulation model (FvGCM), Gao et al. (2008) indicated that resolution plays a crucial role in the simulation of East Asian precipitation during the monsoon season. For extreme precipitation, Huang et al. (2009) revealed that the experiments using the P-σ Regional Climate Model (PσRCM9) under four convection schemes all underestimated the contribution of heavy and torrential rain to the total rainfall over China, but the intensities of the simulated extreme precipitation were quite different during summer.

In recent years, the regional climate model, the Climate version of a Regional Eta-coordinate Model (CREM), was developed by the State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG)/Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences. The model has

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shown reasonable capabilities in simulating the spatial distributions of the summer climatological mean precipitation and circulation (Shi et al., 2009), the rainfall pattern during the ENSO decaying summer (Zeng et al., 2011), the intraseasonal oscillation of summer rainfall (Zhao et al., 2011), and the summer extreme temperature (Zeng et al., 2011) over East China. However, the performance of the model in dynamically downscaling extreme precipitation is unknown. The main motivation of this study is to assess the performance of CREM in simulating the summer extreme precipitation in East China.

The remainder of the paper is organized as follows: descriptions of the model, data, experimental design, and methodology are given in Section 2; Section 3 details the results; and Section 4 summarizes our conclusions.

2 Data and methodology

2.1 Model, data, and experimental design

The model used in the study is CREM, whose dynamical core is based on the IAP GCM (Liang, 1986; Zeng et al., 1989). The horizontal resolution is approximately 37 × 37 km, with horizontal grid numbers of 101 (meridional) × 161 (zonal) and 32 unevenly vertical levels. The buffer zone near the lateral boundary includes 10 grids. For further details of CREM, please refer to Shi et al. (2009).

Data from the National Centers for Environmental Prediction-Department of Energy (NCEP-DOE) Reanalysis (hereafter, NCEP2) (Kanamitsu et al., 2002) are used as the initial and lateral boundary conditions for CREM. The driving fields are six-hourly intervals, and the spatial resolution is 2.5°×2.5° (latitude × longitude). The SST forcing is from the weekly Optimally Interpolated Sea Surface Temperature (OISST) data with a resolution of 1°×1° (Reynolds et al., 2002). The model is integrated starting from 1 April through 31 August during each year of 1982–2007. The simulated domain covers most regions of China (18–48°N, 95–135°E), excluding the buffer zone. The current study focuses on East China (20–40°N, 105–125°E). Also, considering the effect of the spin-up process, our analysis focuses on June to August (summer) during each simulated year.

To evaluate the performances of CREM, the daily gridded precipitation dataset from the Asian Precipitation-Highly-Resolved Observational Data Integration Towards Evaluation (APHRODITE) project (APHRO_MA_1003R1) (Yatagai et al., 2009), zonal wind, meridional wind, and specific humidity from NCEP2 during 1982–2007 are used as observations.

2.2 Methodology

To quantitatively describe extreme events, three precipitation indices are used as follows: 1) the probability density function (PDF), which is used to show the occurrence probability of precipitation at different intensity levels; 2) extreme precipitation, defined as the accumulated precipitation of daily precipitation amounts greater than the 95th percentile of all wet days (R95p); and 3) the percentage contribution from the R95p to the total precipitation amount (R95pt) (Peterson, 2005; Li et al., 2011).

In addition, precipitation intensity, defined as the mean precipitation on wet days (precipitation >1 mm d^{-1}) (SDII), is used.

3 Results

3.1 Probability density function

PDFs of precipitation intensity over North China (NC), the Yangtze River Basin (YRB), and South China (SC) are shown in Figs. 1a, 1c, and 1e. In the observations, the leading precipitation intensities over NC, YRB, and SC are approximately 2 mm d^{-1}, 4 mm d^{-1}, and 6 mm d^{-1}, respectively. For these three sub-regions in East China, the PDFs of precipitation intensities are reasonably reproduced by CREM. However, the model significantly overestimates the dominant precipitation intensities by approximately 1.5 mm d^{-1}, 3 mm d^{-1}, and 3 mm d^{-1} over NC, YRB, and SC, respectively. Also, CREM generally simulates wider extensities of precipitation intensities with less light rainfall and more heavy rainfall. Meanwhile, the maximal precipitation intensities over NC, YRB, and SC are 14 mm d^{-1}, 19 mm d^{-1}, and 21 mm d^{-1}, respectively, from the observations. It is apparent that CREM overestimates the maximal precipitation intensities by approximately 7 mm d^{-1} over NC, 10 mm d^{-1} over YRB, and 12 mm d^{-1} over SC, indicating that the maximal precipitation intensities are overestimated in the model by approximately 50% over most parts of East China.

3.2 Extreme precipitation

The extreme precipitation amounts (R95p) and the percent errors are shown in Figs. 2a, 2c, and 2e. The observed (Fig. 2a) and simulated (Fig. 2c) spatial distributions of R95p are consistent with their precipitation intensities on wet days (SDII) (figures not shown). The maximum centers for R95p are located in the SC and YRB regions with values greater than 200 mm. The minimum center for R95p is situated in northwestern China, with a value lower than 40 mm.

The spatial distribution of R95p is reasonably reproduced by CREM (Figs. 2a and 2c). The spatial correlation coefficient (SCC) of R95p between CREM and the observation is 0.72, and the root mean square error (RMSE) is 120.80 mm. It can be seen that CREM severely overestimates R95p over most of East China and slightly underestimates R95p along the coast lines of SC (Fig. 2e).

R95pts are shown in Figs. 2b, 2d, and 2f. In the observations, the R95pt generally decreases from northeast to southwest over East China, with the maximum center lying at NC. The spatial distribution of R95pt is reproduced well by CREM. However, the R95pts over the middle and lower reaches of YRB are underestimated, and the R95pts over NC, SC, and the eastern Tibetan plateau are overestimated. The location of the maximal bias for R95pt is corresponding to that of the minimal bias for

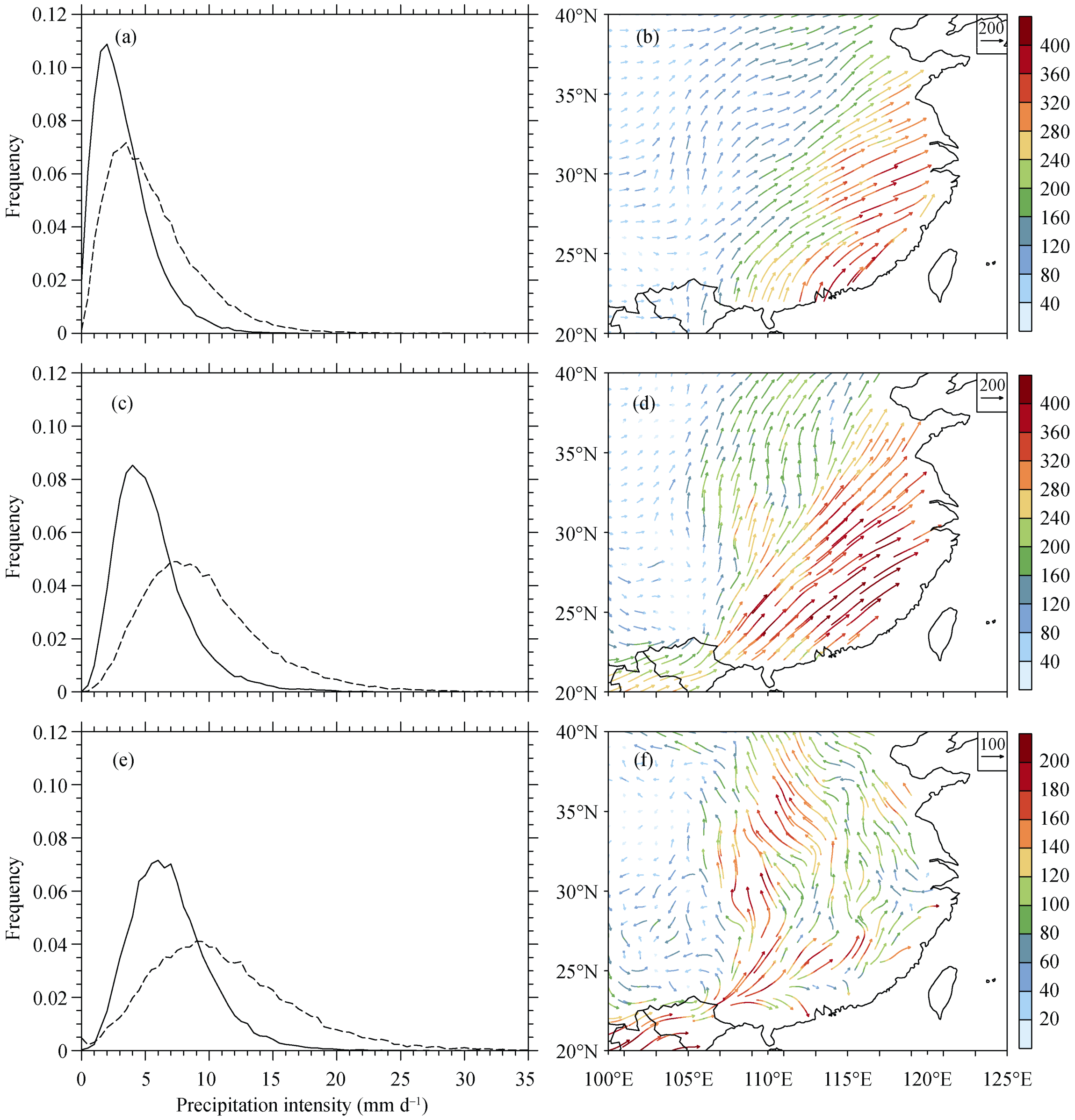

Figure 1 The probability density functions of precipitation intensity from the observations (solid lines) and CREM (dashed lines) over (a) NC, (c) YRB, and (e) SC; the vertically integrated water vapor transport (vectors, units: kg m^{-1} s^{-1}) at each grid associated with the extreme summer precipitation from the (b) observations, (d) simulation, and (f) difference between the simulation and observations.

SDII and vice versa. This result indicates that the bias of P95pt in CREM mainly derives from SDII, which represents the total precipitation amount.

3.3 The interannual variations of extreme precipitation

To evaluate the interannual variations of extreme precipitation simulated by CREM, the interannual series for R95p anomalies (hereafter PC1) and R95pt anomalies (hereafter PC2) in the summer from 1982 to 2007 are shown in Fig. 3. It can be seen that the evolution of PC1 during 1982–2007 is reasonably simulated by CREM. The statistical comparisons are as follows: the correlation coefficients (CCs) of PC1s between CREM and the observations over NC, YRB, and SC are 0.366, 0.747, and 0.754, respectively; the ratios of the standard deviations of PC1s between CREM and the observations are 2.755, 1.355, and 1.226, respectively. In general, the interannual variabilities of extreme precipitation from CREM are larger than the observed values. It is clear that the ability of CREM to simulate PC1s increases from north to south.

However, PC2 is poorly simulated by CREM, especially in SC. The statistical comparisons are as follows: the CCs of PC2s between CREM and the observations over NC, YRB, and NC are 0.373, 0.237, and –0.048, respectively; the ratios of the standard deviations of PC2s between CREM and the observed results are 1.06, 1.084, and 1.432, respectively. Larger interannual variabilities for R95pt are simulated by CREM compared with those of the observations. Also, it can be seen that the ability of CREM to simulate PC2s decreases from north to south, and the model's performance is poor.

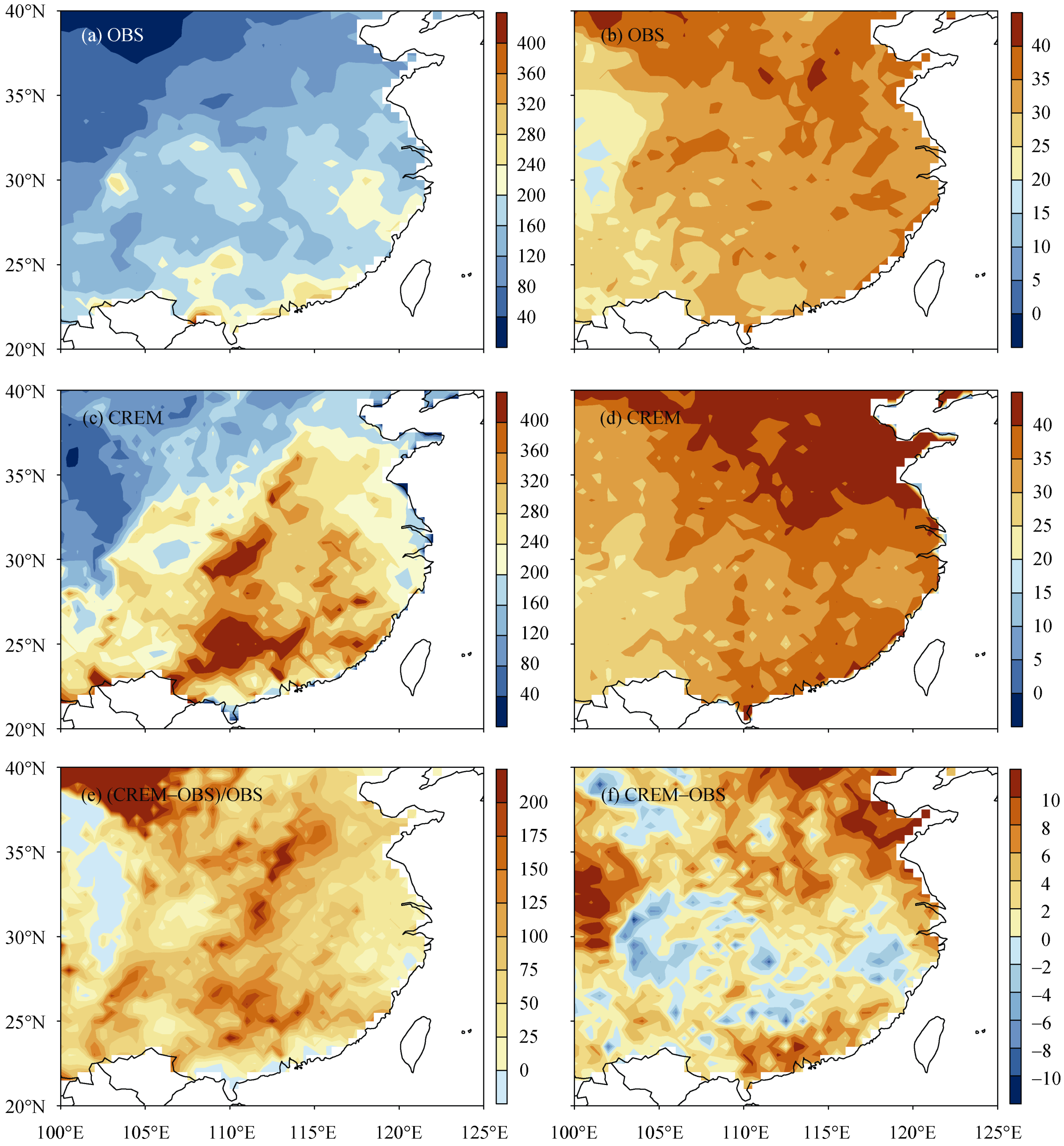

Figure 2 (a, c, e) Same as Fig. 1 (b, d, f), respectively, but for R95p (units: mm) and the percent difference between the simulation and observations in (e). (b, d, f) are the same as Fig. 1 (b, d, f), respectively, but for the percent contribution from the R95p to R95pt (units: %).

3.4 The reason for simulation bias of extreme precipitation

Shi et al. (2009) concluded that CREM had the deficiency of a northward shifted rain-belt over eastern China in the summer that is closely related to the bias in the thermal contrast between central China and southern China, which might result in an intensified zonal wind in the lower troposphere and cause more moisture transport northward. Zeng et al. (2011) revealed that the stronger northward water vapor transport in the lower troposphere led to the stronger magnitude of above-normal rainfall during El Niño decaying summers in CREM.

To determine the reasons for the bias of extreme precipitation, Figs. 1b, 1d, and 1f show the vertically integrated water vapor transport (WVTr95) associated with the extreme summer precipitation at each grid averaged from 1982 to 2007. Both in the observations and model simulation, the southerly WVTr95s play a leading role over East China, which indicates stronger southerly moisture transports to East China when extreme precipitation events occur. However, much stronger southerly WVTr95s are simulated by CREM relative to those in the observations over East China. Thus, the stronger southerly moisture transport may be the main origin for the bias of extreme precipitation simulated by CREM.

4 Summary

This paper evaluates the performance of CREM in

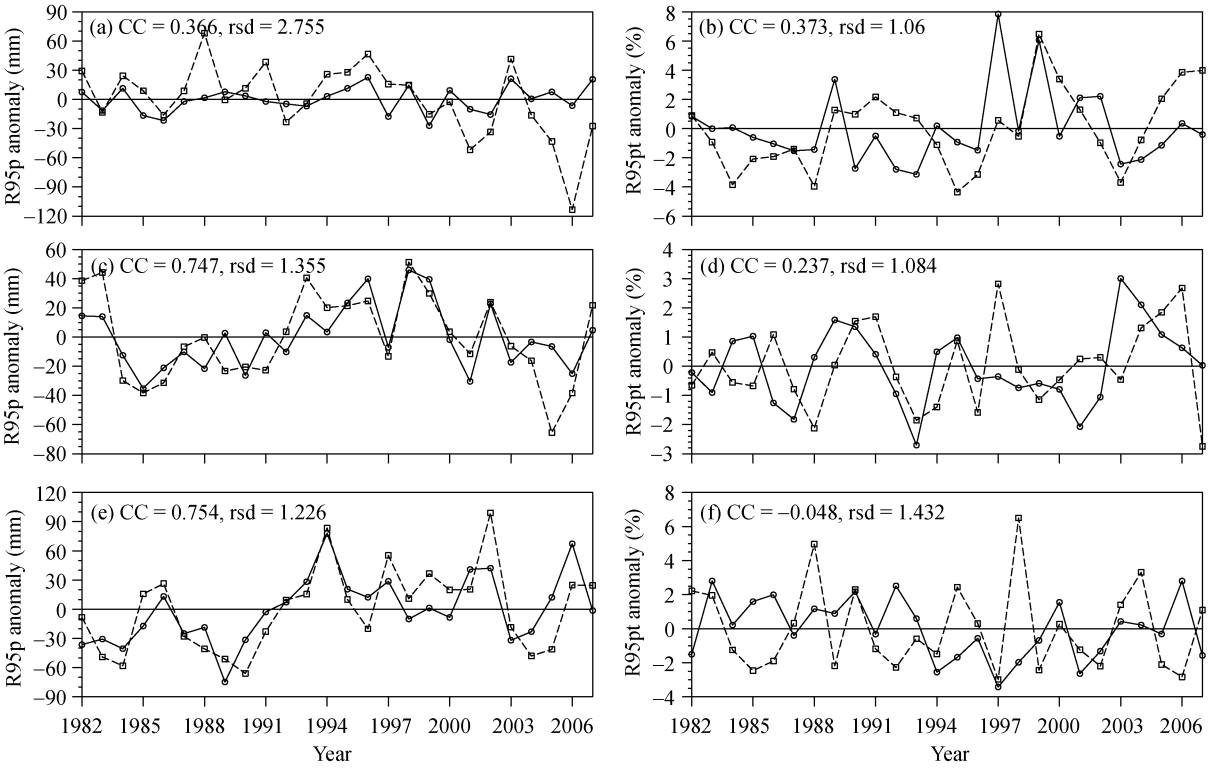

Figure 3 The interannual variations for R95p anomalies (PC1, left panel) and R95pt anomalies (PC2, right panel) in the summer from 1982 to 2007 according to observations (solid lines) and CREM (dashed lines) over (a, b) NC, (c, d) YRB, and (e, f) SC.

simulating the summer extreme precipitation over East China. The results are summarized as follows.

(1) The PDFs for precipitation intensities are reasonably reproduced by CREM. However, the PDFs of light and moderate rain are underestimated, while the PDF of heavy rain is overestimated. CREM overestimates the maximal precipitation intensities by approximately 50% over most parts of East China.

(2) The spatial patterns for the R95p and the R95pt are both well simulated by CREM. However, the R95p and R95pt are generally overestimated over most parts of East China. In addition, the bias of P95pt in CREM mainly comes from SDII, which represents the total precipitation amount.

(3) The PC1s are well reproduced by CREM, whereas PC2s are poorly simulated. The ability of CREM in simulating PC1s (PC2s) increases (decreases) from north to south.

(4) Much stronger southerly water vapor transports associated with the WVTr95 over East China are produced by CREM compared with those of the observations. Meanwhile, the WVTr95 simulated by CREM exhibits a cyclonic circulation bias over most of East China and an anti-cyclonic circulation bias over the coastal area over SC. This deficiency may be the main origin of bias for the extreme precipitation simulated by CREM.

CREM generally simulates more frequent extreme precipitation events, which was also seen in Shi et al. (2009). Shi et al. (2009) concluded that the precipitation parameterization scheme, especially the parameterization of the convective process, may be also a reason for the bias.

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