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AN ANALYSIS OF THE WINTER EXTREME PRECIPITATION EVENTS ON THE BACKGROUND OF CLIMATE WARMING IN SOUTHERN CHINA

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Abstract: Based on daily precipitation and monthly temperature data in southern China, the winter extreme precipitation changes in southern China have been investigated by using the Mann-Kendall test and the return values of Generalized Pareto Distribution. The results show that a winter climate catastrophe in southern China occurred around 1991, and the intensity of winter extreme precipitation was strengthened after climate warming. The anomalous circulation characteristics before and after the climate warming was further analyzed by using the U.S. National Centers for Environmental Prediction/National Center for Atmospheric Research reanalysis data. It is found that the tropical winter monsoon over East Asia is negatively correlated with the precipitation in southeastern China. After climate warming the meridionality of the circulations in middle and high latitudes increases, which is favorable for the southward movement of the cold air from the north. In addition, the increase of the temperature over southern China may lead to the decrease of the differential heating between the continent and the ocean. Consequently, the tropical winter monsoon over East Asia is weakened, which is favorable for the transport of the warm and humid air to southeastern China and the formation of the anomalous convergence of the moisture flux, resulting in large precipitation over southeastern China. As a result, the interaction between the anomalous circulations in the middle and high latitudes and lower latitudes after the climate warming plays a major role in the increase of the winter precipitation intensity over southeastern China.

Key words: extreme precipitation; climate warming; Generalized Pareto Distribution; tropical winter monsoon over East Asia

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1 INTRODUCTION

Extreme weather events refer to the weather events that infrequently or rarely occur in one place or area in terms of statistical distribution[1, 2] . Whereas, the extreme climate denotes that the average situation of the weather events during a certain period of time is extreme, or the extreme weather events occur continuously during that period. The extreme weather used to be defined by experience or whether it has significant impact on society and economy. However, it must be judged by a threshold value of meteorological elements for the purpose of quantitative research, such as daily precipitation of more than 100 mm is defined as an extreme rainstorm event[3-5]. The Fourth Assessment Report of Intergovernmental Panel of Climate Change (IPCC)[6], based on the probability distributions of meteorological elements, defined an event which occurred less than or equal to the tenth percentile (greater than or equal to the 90th percentile) as the extreme event. Moreover, standard variance can also be used as a criterion of extreme events, such as the event with the anomaly greater (less) than 2σ (- 2σ), or twice the standard deviation.

According to the IPCC AR4[6], the total temperature increase from 1850–1899 to 2001–2005 is 0.76°C (0.57°C to 0.95°C) , the best estimate for the low scenario (B1) is 1.8°C (with a likely range of 1.1°C to 2.9°C), and the best estimate for the high scenario (A1FI) is 4.0°C (with a likely range of 2.4°C to 6.4°C). The extreme precipitation events will vary remarkably in both frequency and intensity along with the rising average global surface temperature[7]. A number of scientists have previously noticed the serious consequences resulting from extreme climate variations on the background of global warming[8]. The Second

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and Third Assessment Reports of IPCC[9, 10] particularly described and summarized the observational results of the extreme temperature and precipitation. At present, most of climatologists think that the extreme precipitation events may response very sensitively to the global climate change. In the context of global warming, it is very likely that the heavy precipitation tends to increase significantly. Even if the average total precipitation would decrease or remain invariable, it may result in the increase of the intensity and frequency of heavy precipitation[5]. The regional extreme precipitation trends in China are essentially consistent with the global trends. However, its main features demonstrate obvious regionality and locality[11].

In the past few decades, an evidently increasing trend of precipitation occurred mainly in western China, especially, a rising trend of precipitation days occurred in northwestern China. In the meantime, the precipitation trend in eastern China has a large regional difference, especially in the Yangtze River valley and the south of the river where the precipitation increases, which is mainly manifested through the rising trend of extreme precipitation days. However, the precipitation in northern China tended to reduce, which was mainly reflected in the reduction of extreme precipitation days (with remarkable reduction in some of the stations). The total precipitation variations were not obvious in terms of the average precipitation in China, but the precipitation days were reduced to a somewhat lesser extent[12, 13]. This characteristic indicates the invariance or increase in total precipitation and the reduction in the precipitation frequency is associated with the rising trend of the precipitation intensity, which may result in the increase of flood/drought variability throughout the country. Therefore, it is of importance to find out the intensity variations of the extreme precipitation events, which may help predict the natural catastrophes resulting from the extreme precipitation events and improve the capabilities in disaster mitigation.

The calculation of GPD (Generalized Pareto Distribution) return values is an effective way to discuss and evaluate the extreme event intensity and frequency. In recent years, some scientists utilized GPD to analyze the extreme weather events, such as Paeth and Hense[14] and Jagger and Elsner[15], who carried out analyses of the extreme precipitation, temperature, and hurricanes by means of GPD return values. Not only are the GPD return values applicable to the positive anomaly analysis of extreme events but to the negative anomaly analysis. Cebrian and Abaukkea[16] analyzed and discussed the drought events through calculating the GPD return values of precipitation.

Nowadays there is more discussion of extreme events in summer is than those in winter. In early 2008 a disastrous extreme event of freezing rain and snow occurred in southern China and brought about a considerable loss to the social economy and the life of people. Therefore, a study of the winter extreme disasters is essential.

One may ask whether these extreme events are related to the climate warming. In order to answer this question, this article compares the winter extreme precipitation events before and after the climate warming in southern China by calculating the return values of GPD and discusses the impact of climate warming on the winter precipitation in southern China. Besides, the atmospheric circulations before and after the climate warming are analyzed in detail, which will be based for further discussion of the possible reasons that result in the intensity variations of the extreme precipitation events.

2 DATA AND METHODS

2.1 *Data*

Under the influence of the monsoon climate and topography, China has a clear north-south (dry-wet) climate demarcation line (the 800–1000 mm isohyet) along the Qinling Mountains, Han River and Huaihe River[17]. According to the above-mentioned characteristics as well as previous studies, the area of 102.5°–122.5°E, 20°–35°N is selected as the southern part of China in this study.

Based on the surface temperature data of 66 stations in southern China during the winter from 1951 to 2008, a catastrophe time point of the average winter temperature is determined by using the Mann-Kendall method. Then the GPD return values of winter precipitation are calculated by using the 24-h accumulation precipitation of 286 conventional observation stations in southern China during the winter from 1961 to 2008. In this paper, the quantile of the GPD parameter estimation is set at 90% to evaluate with the method of L-moments. The distribution of the selected stations is shown in Fig. 1.

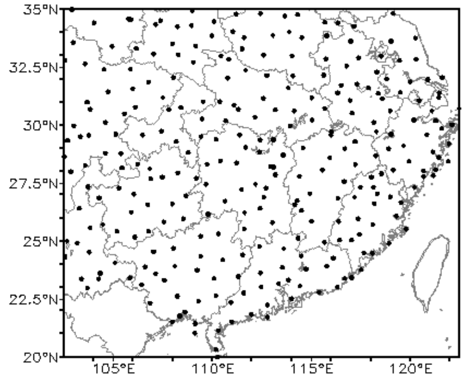

Fig. 1. The distribution of the 286 stations in southern China

In addition, the atmospheric circulation characters before and after the winter climate warming in southern China were analyzed by means of the U.S. National Centers for Atmospheric Prediction/National Center for Atmospheric Research (NCEP/NCAR) monthly reanalyses. The winter average value in this paper is taken for the period from December of the previous year to February of the current year. For instance, the average value taken for the winter of 1961/1962 (the winter of 1962 for short in this paper) refers to that from December 1961 to February 1962.

2.2 *GPD methods*

According to Hosking et al.[18], GPD is usually given in the form of quantile function $X(F)$.

$$x(F)=\zeta+\alpha\frac{1-(1-F)^{\kappa}}{\kappa}. \tag{1}$$

GPD is described by three parameters, namely, the location parameter ζ, which is similar to mathematical expectation of general distribution, scale parameter α and shape parameter κ. When $\kappa\neq 0$, the quantile function is given by Eq. (1), when $\kappa=0$, it is given by Eq. (2):

$$x(F)=\zeta-\alpha\log(1-F). \tag{2}$$

Three GPD parameters are estimated by the method of L-moments[19] for the distribution of the central moment in some respects. The L-moments describe the mean, variance, skewness and kurtosis in ascending order, which have the following advantages in the extreme value analysis:

(1) The method of L-moments represents a wider range of statistical distribution.

(2) The description of the outliers is more stable and unbiased by using this method when it is estimated on a limited sample.

(3) The method of L-moments can be estimated by the linear fit of the order statistic. It is estimated from the random samples of unknown distribution when used in practical applications. X^1, X^2,…, X^n are set as ordered samples and the first three moments are defined as follows:

$$l_1=n^{-1}\sum_i x_i, \tag{3}$$

$$l_2=\frac{1}{2}\frac{2!(n-2)!}{n!}\sum\sum_{i>j}\left(x_{i:n}-x_{j:n}\right), \tag{4}$$

$$l_3=\frac{1}{3}\frac{3!(n-3)!}{n!}\sum\sum_{i>j>k}\sum\left(x_{i:n}-2x_{j:n}+x_{k:n}\right). \tag{5}$$

For GPD parameter estimation, the selected samples must be above a certain threshold. The parameter estimation is given as follows:

$$\hat{k}=\left(1-3\tau_3\right)/\left(1+\tau_3\right),\ \ \tau_3=l_3/l_2, \tag{6}$$

$$\hat{\alpha}=(1+\hat{k})(2+\hat{k})l_2, \tag{7}$$

$$\hat{\zeta}=l_1-(2+\hat{k})l_2. \tag{8}$$

Once these estimated parameters are given, the return values (R_T) of different return periods can be calculated as follows[20]:

$$R_T=\hat{\zeta}+\hat{\alpha}\frac{1-(\lambda T)^{\hat{k}}}{\hat{k}} \tag{9}$$

where λ is the number of extreme events above the threshold per year. Taking the average value of many years in the calculation, T is the return period (also known as the recurrence interval) of the event. The interpretation of T=5 for the precipitation is that in a very long series, the 5-year flood value would be exceeded every 5 years on average.

3 CATASTROPHE TIME OF WINTER SURFACE TEMPERATURE IN SOUTHERN CHINA

Numerous studies and observational facts[21, 22] indicate that there has been a sharp increase of the global mean temperature since the 1980s, but it does not mean an overall tendency of temperature rise in all regions around the world. As a matter of fact, the surface temperature in some areas has a falling instead of rising trend and the catastrophe time point of the regional surface temperature varies by the season. Therefore, the early 1980s cannot be regarded generally as the time of climate catastrophe.

In this paper, the Mann-Kendall test is used to determine the winter catastrophe time of the surface temperature in southern China. Figure 2 shows the Mann-Kendall test of the winter average surface temperature in southern China. In order to highlight the interdecadal climate variation, the winter surface temperature in southern China has been processed by using a 5-year running mean. As can be seen in Fig. 2b, there is a significant catastrophe point of the winter surface temperature around 1991. After 1991 the climate in southern China becomes significantly warmer.

4 COMPARATIVE ANALYSES OF EXTREME PRECIPITATION BEFORE AND AFTER CLIMATE WARMING

Due to the lack of precipitation data in many stations before the 1960s, and in order to ensure the data quality and the accuracy of the calculation, the winter daily precipitation data during 1961–1990 and 1991–2008 were chosen in this paper to calculate the GPD parameters and the extreme precipitation return values, respectively. And the extreme precipitation differences before and after the winter climate warming in southern China were discussed by means of the return values of the extreme precipitation. Considering the stability of the GPD parameter estimation with respect to a range of threshold values, comparison of the GPD return values of 1–20 years has been conducted.

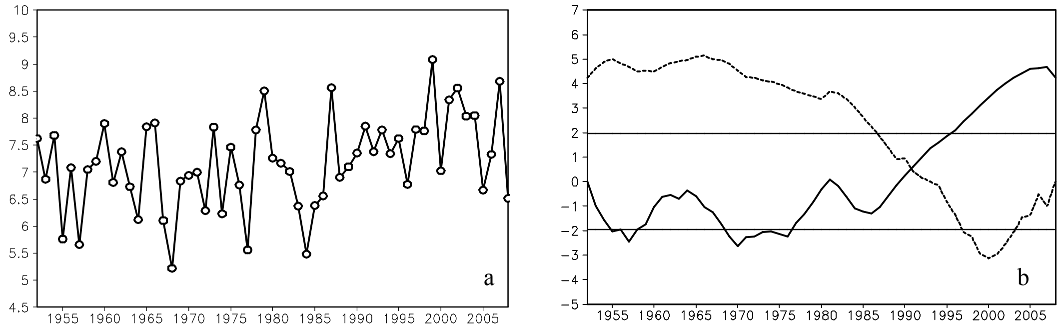

Fig. 2. Interannual variation features (a) and the Mann-Kendall test (b) of the winter surface temperature in southern China during 1952–2008. The solid line represents $U(d_l)$ and the dashed line $U^*(d_l)$.

The 1-year return value distribution (Figs. 3a & 3b) reflects the average conditions of extreme daily precipitation per year. The high-value centers of the extreme daily precipitation before and after climate warming are located in the south of Hunan and Jiangxi provinces and northern Guangdong, while the eastern Sichuan is a low-value region of the extreme precipitation. Before the climate warming the high-value center of extreme daily precipitation is around 25 mm and the low-value center is around 5 mm, while after the climate warming the high-value center has increased by 5 mm to be around 30 mm and the low-value center has moved slightly to the north. Accordingly, the intensity of annual extreme daily precipitation in most parts of southern China has increased in winter after the climate warming, while the extreme daily precipitation in the eastern part of Sichuan, Chongqing, southeastern Gansu, southern Shaanxi, and Henan provinces has decreased slightly. As can be seen in Figs. 3c & 3d, the high-value regions of the extreme daily precipitation which occurred once in five years are located in the southeast of Guangdong and Guangxi before the climate warming while the low-value center is located in the northeast of Sichuan. After the climate warming, the high-value regions of once-in-five-year extreme daily precipitation extend northeastward from the southeast of Guangdong and Guangxi, and the extreme precipitation with evident higher intensity is located in extended areas of the south of the Yangtze River and southern China. While the low-value center has slightly moved to the north, the extreme daily precipitation in the northwest of southern China has decreased. There are similar distribution characteristics of the extreme daily precipitation in the 10-year (Figs. 3e & 3f) and 15-year (Figs. 3g & 3h) return values.

Summarizing the above findings, the intensity of the extreme daily precipitation in the south of southern China has increased after the climate warming, and little change of the extreme daily precipitation intensity has occurred in Guizhou, Hunan, Anhui, Jiangsu provinces, while the intensity of the extreme daily precipitation is weakened somewhat in southeastern Gansu, southern Shaanxi, and Henan provinces.

In order to have better knowledge about the distribution of return values each year before and after the climate warming in southern China, this paper calculated the GPD return values of the regional average daily precipitation with different return periods in southern China (see Fig. 4). As shown in Fig. 4, the average intensity of the extreme daily precipitation in southern China in winter after the climate warming is greater than that before the climate warming by about 2 mm on average, especially, the increase of the extreme daily precipitation intensity of once in 4–10 years is most evident.

Summing up, the intensity of the extreme precipitation in southern China in winter has slightly increased after the climate warming mainly in Guangdong, Guangxi, Fujian and Jiangxi, southern Hunan provinces, instead of the whole southern China. However, the intensity of the extreme precipitation has decreased in the northwest of southern China.

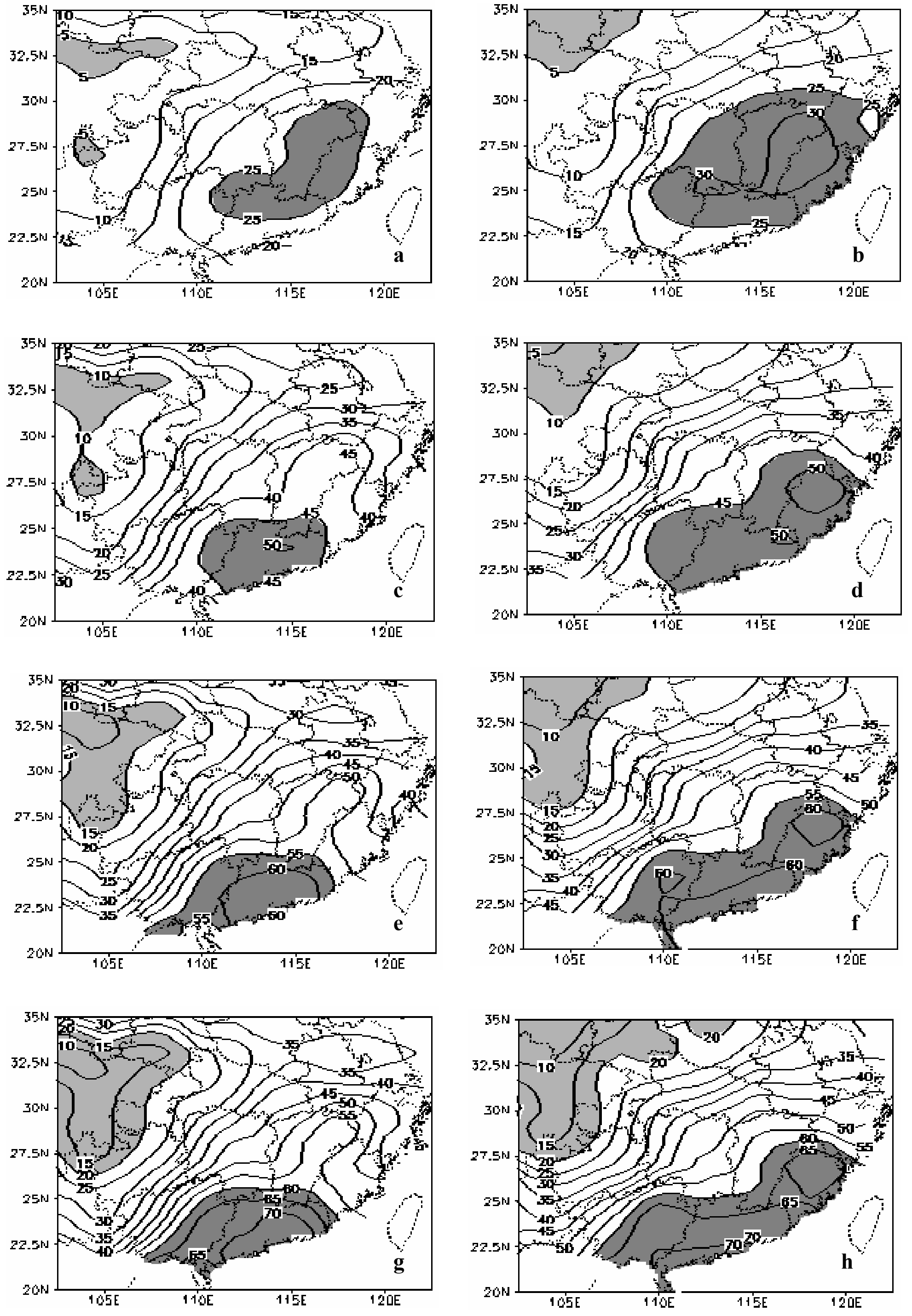

Fig. 3. Distribution of the GPD return values of extreme daily precipitation in winter. The left panels represent the return values for the return periods of 1 year (a), 5 years (c), 10 years (e) and 15 years (g) estimated for the period from 1961 to 1990. The right panels represent the return values for the return periods of 1 year (b), 5 years (d), 10 years (f) and 15 years (h) estimated for the period from 1991 to 2008. (units: mm)

5 COMPARATIVE ANALYSES OF THE ATMOSPHERIC CIRCULATION BEFORE AND AFTER CLIMATE WARMING

It is well known that the change of temperature and precipitation are closely related to that of the atmospheric circulation. The system of East Asian monsoon has a profound influence on the climate of China. Chen et al.[23] defines an index for East Asian tropical monsoon (hereafter denoted as I_{chen}) as the regional average of 10 m meridional wind over the region (10°–25°N, 110°–130°E). The winter meridional wind in East Asia is dominated by the northerly; the smaller the I_{chen} value, the stronger the winter monsoon. The opposite sign of I_{chen} is used and denoted as $-I_{chen}$ in this paper in an attempt to describe the strength of the monsoon more conveniently. In this case, the higher the $-I_{chen}$, the stronger the East Asian tropical monsoon, and vice versa.

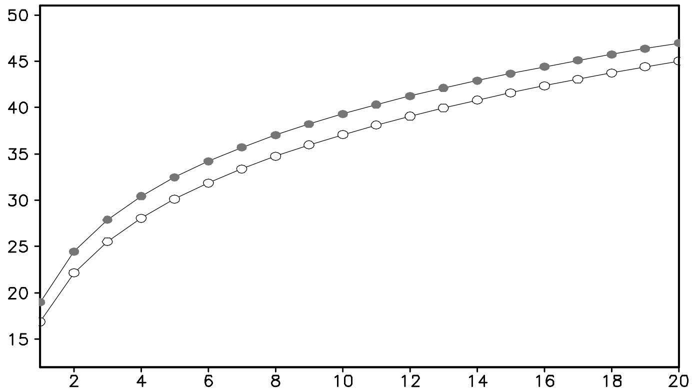

Fig. 4. The GPD return values of the mean daily precipitation over southern China in winter for the period from 1961 to 1990 (hollow circle) and from 1991 to 2008 (solid circle), where the ordinate represents return values (mm) and the abscissa represents return periods (years).

By calculating the correlation coefficient between $-I_{chen}$ and the OLR field, it is found that $-I_{chen}$ is negatively correlated with the OLR over the south of the Yangtze River, southern China and its adjacent regions (figure omitted). When the East Asian tropical monsoon is strong, the convection over the south of the Yangtze River and southern China is weak, and vice versa. A composite analysis on the strong and weak precipitation in winter with the anomalous years of the East Asian tropical monsoon in southern China is conducted to further investigate the relationship between the East Asian tropical monsoon and the precipitation (Fig. 5). Those years with normalized index above 1 (under -1) were selected as the years of stronger (weaker) East Asian tropical monsoon in winter. 1963, 1968, 1974, 1977, 1982, 1984, 1986, 1989, and 1996 are stronger monsoon years, while 1954, 1966, 1969, 1973, 1983, 1998 and 2003 are weaker monsoon years. As shown in Fig. 5, when the tropical winter monsoon is stronger than normal, the precipitation in southeastern China has an evident negative anomaly with the center (less than -20 mm) in the south of the Yangtze River; when the tropical winter monsoon is weaker than normal, however, an obvious positive precipitation anomaly is found in southeastern China with the center (more than 40 mm) in the south of the Yangtze River.

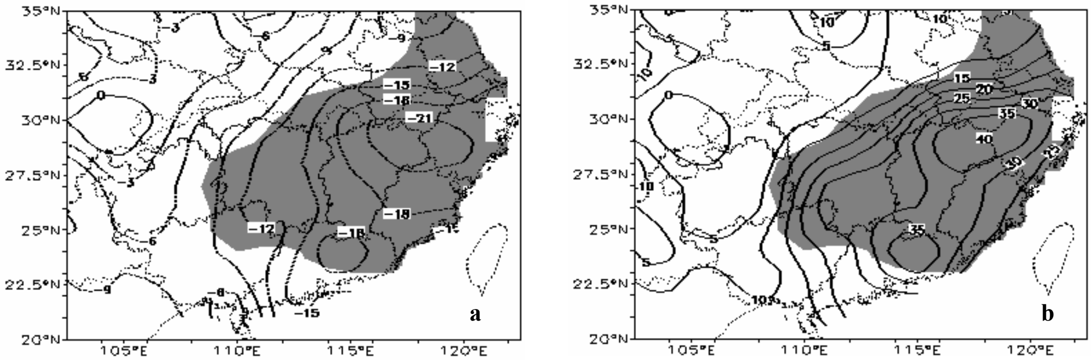

Fig. 5. The composite precipitation anomalies (mm) in southern China in winter during the years of strong (a) and weak (b) tropical winter monsoon over East Asia. Shaded values are significant at the 95% confidence level.

The above analysis suggests that the tropical winter monsoon over East Asia is negatively correlated with the precipitation over southeastern China. When the East Asian tropical monsoon is stronger, the precipitation over southeastern China is weaker, and vice versa.

Figure 6 shows the Mann-Kendall test of the $-I_{chen}$ index for East Asian tropical winter monsoon during 1952–2008. The five-year running mean of the index has been used for highlighting the decadal climate change. As shown in Fig. 6, there are several catastrophe points of the index in the East Asian tropical winter monsoon during 1952–2008. In view of the data quality problems of the NCEP/NCAR reanalyses before the 1980s, this paper focuses on the analysis of circulation catastrophe points after the 1980s. It is found that the East Asian winter monsoon was weakened significantly in the early 1990s. The weak trend of the East Asian tropical winter monsoon is basically similar to the warm trend in southern China, and both have relatively similar catastrophe points in the early 1990s. This may result from the warming trend of the surface temperature, which leads to the decrease of the heating difference between the continent and the ocean, and hence the decline of the East Asian subtropical monsoon.

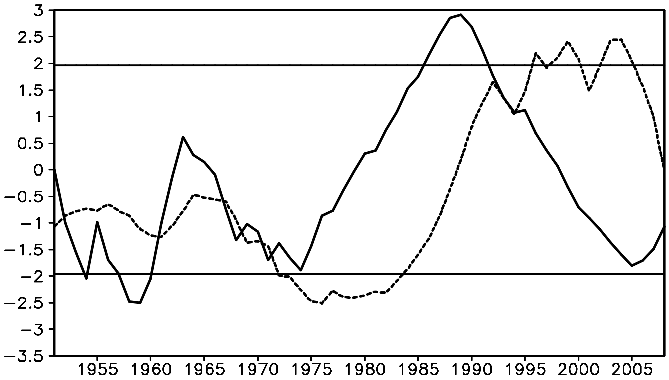

Fig. 6. The Mann-Kendall test of the winter -I_{chen} index during the period from 1952 to 2008. The solid line represents $U(d_i)$ and the dashed line represents $U^*(d_i)$.

In order to further investigate the characteristics of the atmospheric circulation before and after the climate warming in southern China, this paper analyzes the anomalies of the wind and geopotential height fields at 500 hPa relative to their corresponding climate mean fields (See Fig. 7). Comparing the wind fields before and after the warming in southern China, a cyclonic circulation anomaly can be seen over the Ural Mountains region after the climate warming, which is consistent with the changes of the geopotential height field. The shallow trough behind the winter mean ridge at 500 hPa has deepened slightly. Meanwhile, the anomalous anticyclonic circulation occurs over northern China and Mongolia, and the mean ridge over the Lake Baikal region has slightly intensified, which leads to the increase of the meridionality of the circulations in the middle and high latitudes, and is thus favorable for the southward movement of the cold air in the north. In lower latitudes, the westerly affecting the transport of water vapor to southern China is weakened, while the increased southeasterly from the western Pacific is conducive to the movement of warm and humid air to southern China. The interaction between the anomalous circulations in the middle and high latitudes and lower latitudes is favorable for the formation of precipitation over southeastern China when the cold air from the north and the abnormal warm and humid air from western Pacific meet with each other.

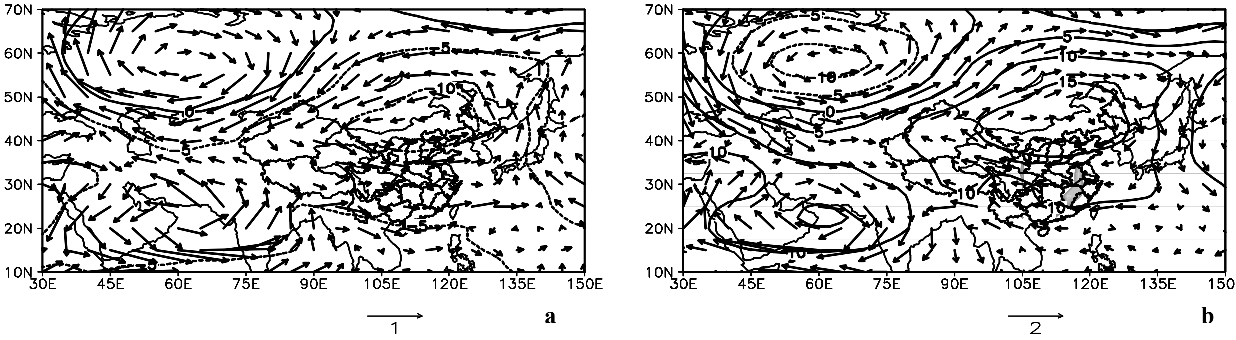

Fig. 7. Anomalous wind fields and geopotential height fields at 500 hPa in winter for the periods from 1961 to1990 (a) and from 1991 to 2008 (b). The abnormal convergence of vertically integrated moisture flux is shaded.

Summing up, the interaction between the anomalous circulations in the middle and high latitudes and lower latitudes after the climate warming plays a major role in the increase of the winter precipitation intensity over southeastern China.

6 CONCLUSIONS

Based on the NCEP/NCAR monthly reanalysis data, the daily precipitation and the winter surface temperature in southern China, the variation features of the winter extreme precipitation event and its circulation on the background of the climate warming were investigated. Main results are summarized as follows.

(1) The catastrophe of winter surface temperature in southern China occurred around 1991 and winter climate in southern China became significantly warmer after 1991.

(2) The average intensity of extreme precipitation over southern China has increased since the climate warming in winter. However, the extreme precipitation in the northwest of southern China has slightly decreased. Before and after the climate warming, the locations of the high-value centers of the extreme precipitation have little variation and stay in southeastern Guangdong and Guangxi provinces.

(3) The tropical winter monsoon over East Asia is negatively correlated with the precipitation over southeastern China. When the East Asian tropical monsoon is stronger, the precipitation over southeastern China is weaker, and vice versa.

(4) The interaction between the anomalous circulations in the middle and high latitudes and lower latitudes after the climate warming plays a major role in the increase of the winter precipitation intensity over southeastern China.

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