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# SPATIO-TEMPORAL VARIATION OF SEASONAL EXTREME WET DAYS IN CHINA AND ITS RELATIONSHIP WITH SST ANOMALIES

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**Abstract:** With daily precipitation records at 586 stations in China for 1960-2004, this study investigates the spatio-temporal variation of the number of extreme wet days (NEWD) for each season in China and its relationship with SST anomalies and associated atmospheric circulation anomaly patterns, in which a threshold of extreme precipitation for a season and a station is defined as the value of the 90th percentile when the precipitation records for wet days during the season are ranked in an increasing order. Results show that there are significant increases of the NEWD along the Yangtze River valley during winter and summer, in North China during winter, in South China during spring, in Northeast China during winter and spring, and in Northwest China throughout the seasons, while there is a remarkable decrease in North China during summer. Besides the linear trend, the NEWD also exhibits considerable interannual and interdecadal variabilities. After eliminating the linear trend, the NEWD anomalies show distinct seasonal patterns. The NEWD anomalies are characterized by a “dipole” mode with opposite phases between northern and southern China in spring and autumn, a “tri-pole” mode with opposite phases between Yangtze River valley and southern and northern China in summer, and a “monopole” mode with the same phase over most of China in winter. The relationship of the NEWD anomalies in China with the SST anomalies in Indian and Pacific Oceans is found to be mainly dependent on the ENSO, and associated atmospheric circulation anomaly patterns for the ENSO’s impact on the NEWD in China are identified.

**Key words:** extreme precipitation; number of extreme wet days; SST anomaly; ENSO

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## 1 INTRODUCTION

The change of extreme weather and climate events under the background of global warming has been one of the important issues in climate change research. Flood or drought is a type of extreme weather and climate event and its long-term trend is characterized by significant regionality and seasonality. Previous studies showed that during the recent half century, the precipitation in most part of the world increased significantly, and the frequency of the extreme precipitation also increased correspondingly[1-6]. Osborn and Jones[7] found that in the UK there was a positive trend of the extreme precipitation events in winter, but in summer the trend became negative. Manton et al.[8] showed that in most part of Southeast Asia, the proportion of the annual precipitation taken by the extreme precipitation events increased, while the number of these events decreased. Rakhach and Soman[9] found that in some regions of India, the extreme precipitation increased obviously, but in some other regions, it shows an opposite trend.

The characteristics of the extreme precipitation in China have also been analyzed in a number of previous studies. The trend of the total precipitation in China is not significant, but that of the number of the wet days decreases obviously[10-12]. Along with the significant decreasing of the wet days in China, the precipitation became much stronger in most of Northwest China, the middle and lower reaches along the Yangtze River as well as part of South China, thus more extreme precipitation events occurred in those regions while less happened in North China and Sichuan Basin[10-11,13-16]. The trend of precipitation of

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China was found to be seasonally dependent. The increasing trends of precipitation mainly happened in summer in East China, and the decreasing trends mainly happened in spring and autumn in Northeast China, North China and middle China, while there are increasing trends in all seasons in most region in Northwest China[17, 18]. In the past few decades, there is a tendency toward increased droughts in northern China and increased floods in Yangtze River valley[19, 20]. Su et al.[21] stated that the extreme precipitation events along the middle and lower reaches of the Yangtze River also have a significant increasing trend. The frequent occurrence of flood along the Yangtze River since the 1990s and the temporal and spatial distribution of the extreme precipitation in this region have shown a close correlation.

Concerning the extreme precipitation in China, there still exist some issues that need to be further investigated. First, how do we objectively define the threshold of extreme precipitation? The definition of the threshold can have a great impact on the conclusions. Conventionally, a fixed threshold (say, 50 mm/d）is used to study such a topic. But in fact this method is defective because it cannot describe geographical and seasonal discrepancies of the thresholds. Second, the precipitation in many regions of China exhibits significant interannual and decadal variabilities[19, 22-29]. However, most of previous studies are usually concerned about the long-term trend of the extreme precipitation, the interannual and decadal variations of the extreme precipitation are not clearly documented. Third, how does the extreme precipitation in China vary in different seasons? Is its variation consistent from one season to another? Fourth, the SST anomaly is one of the crucial factors affecting the climate of China[30-38]. What is the relationship between the extreme precipitation in China and the SST anomalies? In this paper, we use daily precipitation records for the past 45 years in China to address the above issues by defining extreme precipitation thresholds that vary with station and season.

## 2 DATA AND METHOD

The dataset used in this study includes the daily precipitation records at 586 stations in China for January 1, 1960 to December 31, 2004. This dataset is provided by National Climate Center of China Meteorological Administration. The dataset also includes the global sea surface temperature and the global atmospheric reanalysis data from 1960 to 2005. The monthly SST data is provided by UK Met Office, namely GISST (Global Sea Surface Temperature Date Set) data with 1°×1° resolution. The atmospheric reanalysis data is provided by National Centers for Environmental Prediction / National Center for Atmospheric Research (NCEP/NCAR, USA) with 2.5°×2.5° resolution.

There are different methods to define the extreme precipitation. A simple way is to use a fixed daily precipitation value as the threshold and then consider the situation with daily rainfall exceeding the threshold as an extreme event. Usually such a value is set to be 50 mm/d to indicate heavy rain in China. Nevertheless, there are considerable regionality and seasonality in precipitation in China. The precipitation is above the average in southern and eastern China but below the average in northern and western China, and also most of the precipitation is concentrated in the summer season. It is inappropriate to use a fixed threshold to analyze the extreme precipitation event in China. An objective way is to define the threshold with a value at a certain percentile. For a certain synoptic phenomenon, when its state deviates from its climatology severely, it can be considered as an infrequent event or extreme event in terms of statistics. Suppose that a meteorological variable has $N$ values. Then we rank them, in an increasing order, into a sequence: $X_1$, $X_2$, $X_3$, …, $X_N$, and in terms of the Gamma distribution we define the value at a certain large percentile (say, 90th) as a threshold. According to such a definition, the values larger than the threshold are classified into extreme events. In this paper, we use the value on the 90th percentile of the sequence as a threshold. Such a definition will strengthen the spatial comparability between the dry and wet regions as well as the temporal comparability between the dry and wet seasons.

The daily precipitation data for 30 years (1971 to 2000) is used to climatologically estimate a threshold for extreme events. For a given station and a given season, a day with daily precipitation no less than 1 mm is said to be a wet day. We rank, in an increasing order, the daily precipitation for all the wet days during the season for the 30 years, and determine a threshold of extremum in terms of the 90th percentile. Then we can obtain the threshold of extreme daily precipitation for each station in China and for each season. A day with daily precipitation larger than the threshold is said to be an extreme wet day. Then we can count the number of extreme wet days (NEWD) for each season in the past 45 years (1960 to 2004).

## 3 SPATIO-TEMPORAL VARIATION OF SEASONAL NUMBER OF EXTREME WET DAYS

Figure 1 shows spatial distribution of the linear trends of the seasonal NEWD in four seasons for 1960 to 2004. In spring, the NEWD increased significantly in regions such as Southwest China, Northwest China, North China and most part of Northeast China in which the positive trend in Southwest China is the most prominent (Figure 1a). In summer, the extreme precipitation events became more frequent along and south of the Yangtze River valley, in the southwest and northwest of China, but less frequent in Sichuan Basin, North China as well as the south of Northeast China (Figure 1b). The NEWD in autumn increased significantly in regions such as the west of China, Northeast China and part of the middle reach of Yangtze River, whereas it decreased in the other parts of China (Figure 1c). The wintertime extreme wet days showed increasing trends nearly all over the country, especially in the middle and lower reaches of Yangtze River, the west of Northwest China, North China and east of Northeast China (Figure 1d). In summary, during the past 45 years, in Yangtze River valley the NEWD increased significantly during summer and winter, while in North China it increased significantly in winter but decreased markedly in summer. In South China, the increased NEWD happened strongly in spring. In Northeast China, it happened in winter and spring. Moreover, in Northwest China, a prominent positive trend occurred in every season.

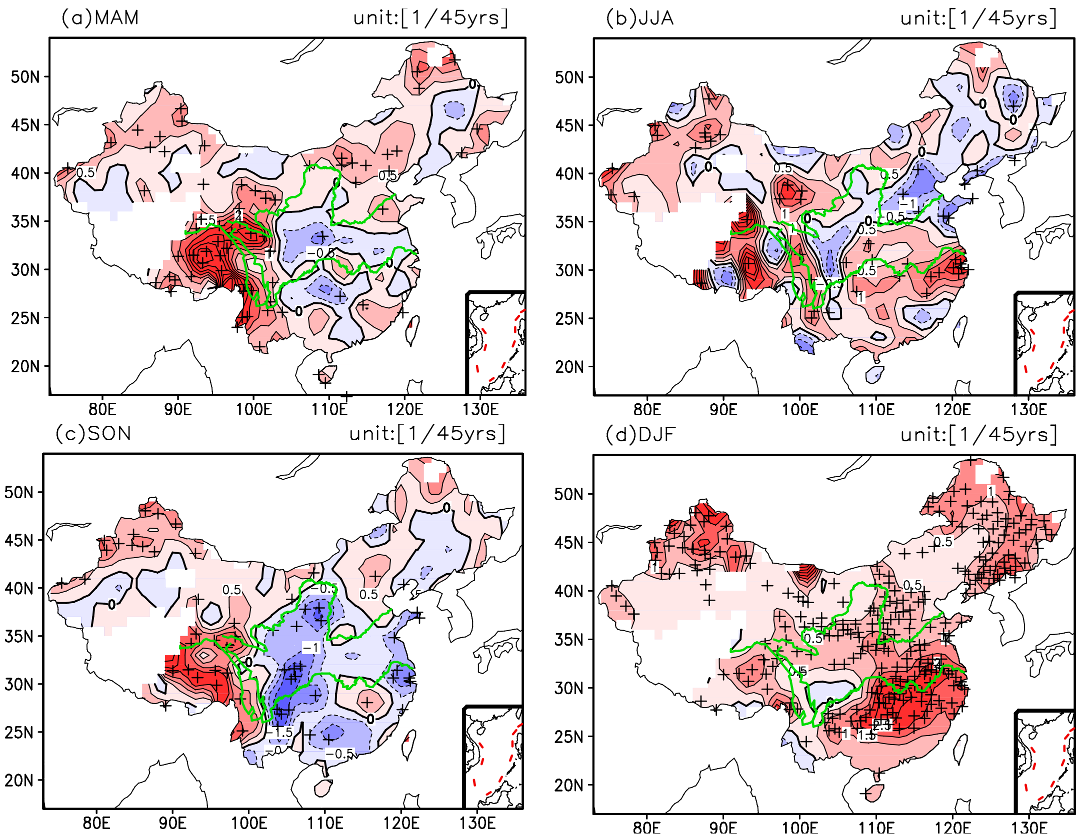



**Figure 1.** Spatial distribution of the linear trends of the seasonal number of extreme wet days in China for (a) spring, (b) summer, (c) autumn, and (d) winter in 1960-2004.

We choose two typical regions, the middle and lower reaches of Yangtze River (110°E–121°30′E, 28–32°N) and North China (110°E–120°30′E, 35–38°N), to investigate how the NEWD varies interannually. Figure 2 shows the time series of the summertime NEWD averaged over these two regions. The NEWD has an obvious increasing trend in Yangtze River valley, roughly with 0.9-d increase within 45 years. Meanwhile, in this region we can also see clear interannual variability. There is no significant trend during the period between the 1960s and 1970s, only with an interannual oscillation. However, from the 1980s to end of the 20th century, the increasing trend became more significant; but such a trend is reversed at the beginning of the 21st century. In North China, the NEWD became less frequent in the past 45 years as a whole, and interannual and interdecadal variabilities are superimposed upon the linear trend. The trend of the summertime NEWD shown in Figure 2 agrees well with the observed pattern of southern-flood versus northern-drought in China[34].

The analysis above exhibits the characteristics of the linear trend of the seasonal NEWD in China. By eliminating this linear trend, we can further investigate the spatio-temporal variation features of the NEWD anomalies with the EOF analysis method. Figure 3 shows the leading EOF mode and associated principle component of the NEWD for each season. It can be seen that, in spring and autumn, the patterns are very similar, characterized by a “dipole” mode with opposite phases between northern and southern

China; in summer, the pattern appears to be a "tri-pole" mode with opposite phases between Yangtze River valley and southern and northern China; while in winter, it is characterized by a "monopole" mode with the same sign almost everywhere in China but with the anomaly most significant in southern China. From the corresponding time series (PC1), we can find that the common features of different seasons are that the variations are mostly on interannual and interdecadal scales.

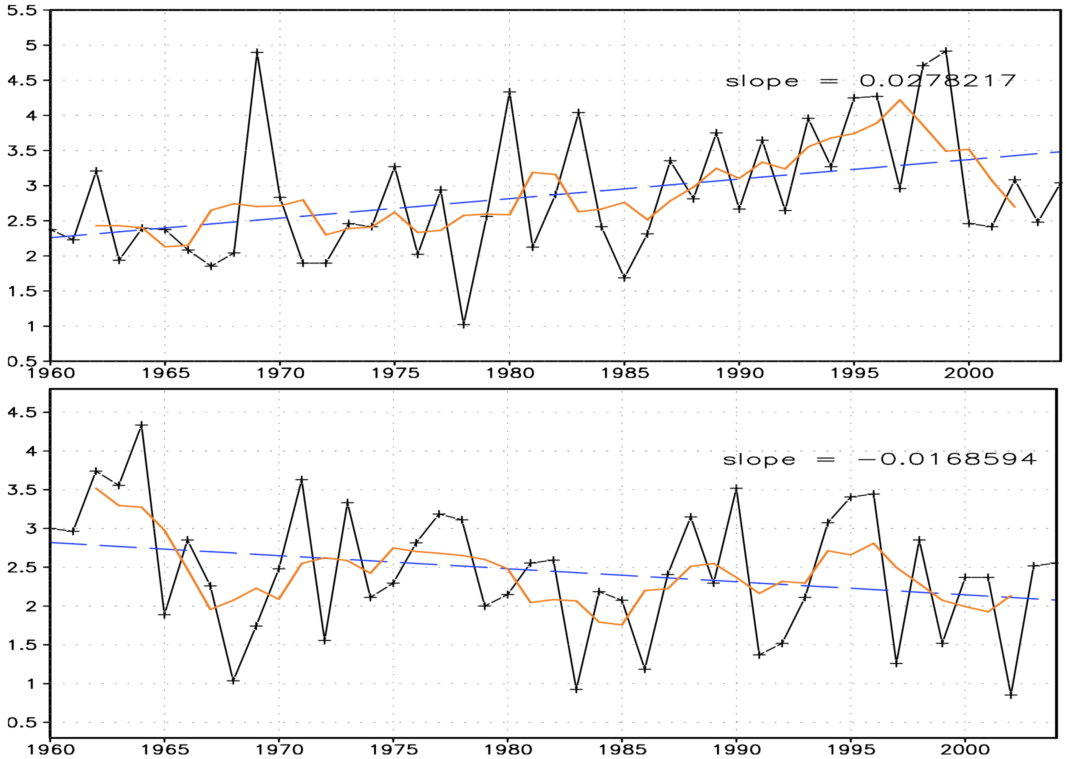



**Figure 2.** Time series of the summertime number of extreme wet days averaged over Yangtze River valley region (top panel) and North China (bottom panel). Note that the blue dashed straight line indicates the linear trend and red line the 5-yr running mean.

## 4 RELATIONSHIP OF SEASONAL NUMBER OF EXTREME WET DAYS WITH SST ANOMALIES

A variety of previous studies have investigated the relationship between the SST anomalies and the climate variations in China. However, the relationship between the SST anomalies and the extreme precipitation anomalies in China remains unclear. To avoid interference of linear trend of the relationship between two variables, each variable used in the following analysis has been detrended. The Singular Vector Decomposition (SVD) analysis has been made to investigate simultaneous coupled relationship between the anomalous NEWD in China and the SST anomalies in Indo-Pacific oceans. The leading SVD mode can explain covariance of 43% for winter, 42% for spring, 37% for autumn and 20% for summer. The correlation coefficient of the time series for the two variables associated with the first SVD mode is 0.65 in winter, and reaches or exceeds 0.85 in the other three seasons.

Figure 4 shows the spatial distributions of the hetero-correlation fields and their corresponding time series for the leading SVD mode. The spatial distributions of SST anomalies in different seasons all appear to be the El Niño pattern, suggesting that the relation of the extreme precipitation in China to SST anomalies is primarily associated with ENSO. However, the distributions of the Indo-Pacific SST anomalies in different seasons are not exactly the same, reflecting the distinct phases of El Niño's evolution. Corresponding to each El Niño phase (season), the distribution of anomalous NEWD in China also shows unique features. In spring, the NEWD increases mainly in North China, Northeast China and some parts of Northwest China, whereas in Southwest China, it decreases remarkably. In summer, it increases along Yangtze River as well as in most of Northeast China and decreases in North China. However, we should note that the correlation in summer is insignificant. In autumn and winter, the NEWD increases obviously in South China. The time series of the leading SVD mode for all seasons vary mainly on the interannual timescale, reflecting the characteristics of SST anomalies during different El Niño phases. Specifically, autumn and winter are corresponding to the mature phase of an El Niño event, while spring is corresponding to its decay phase. But summer that seems to be a little complex includes either the onset phase or the decay phase. That is why the relationship between SST anomalies and the simultaneous anomalous NEWD is insignificant. Since the evolution of an ENSO event largely depends on seasons, the investigation of the influence of ENSO must be based on its different phases.

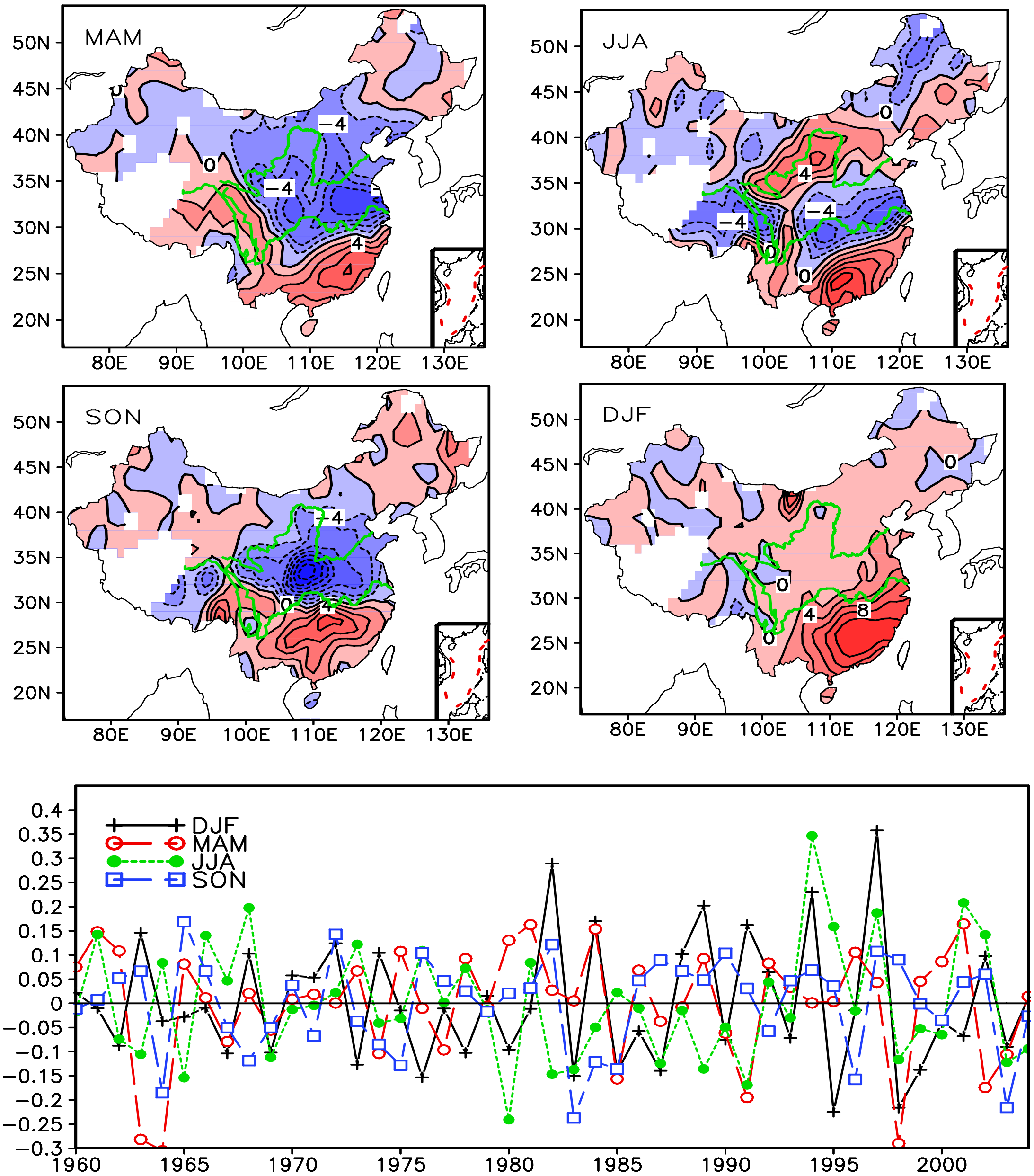
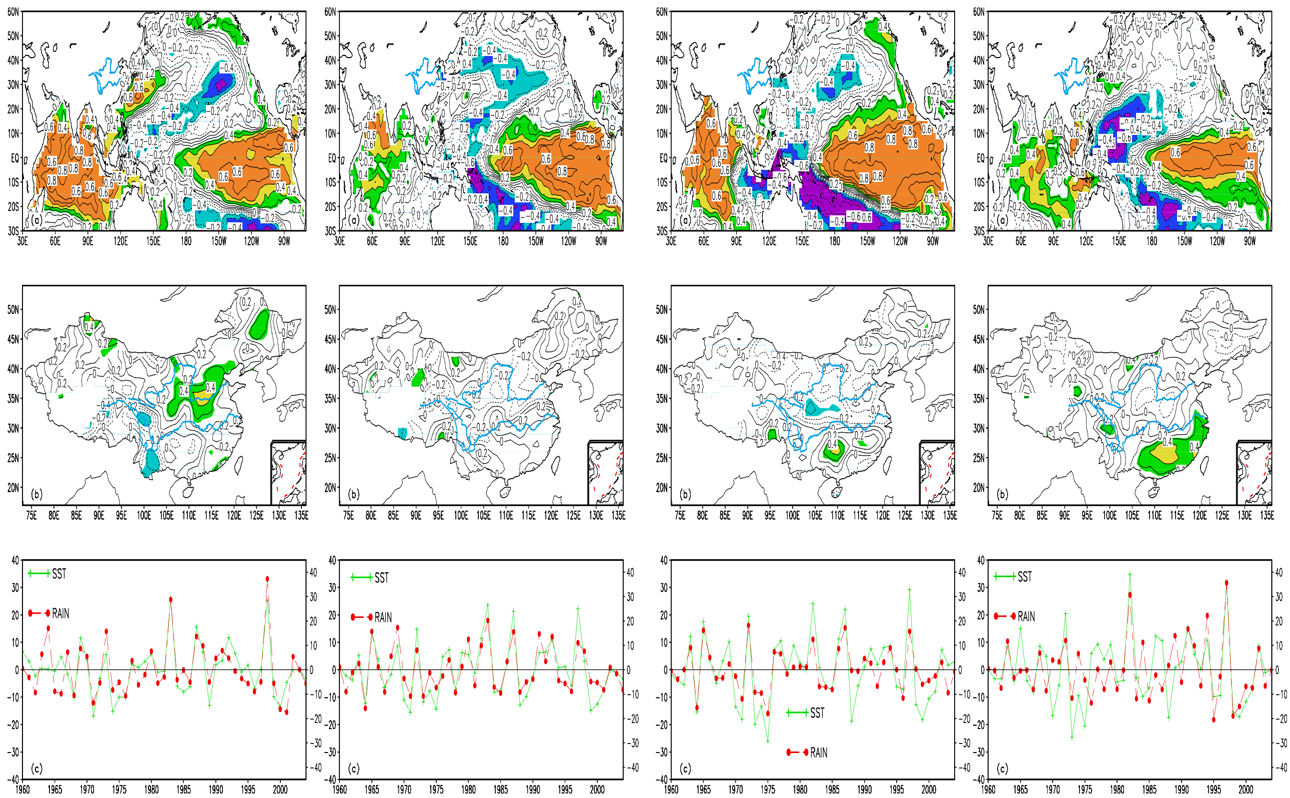



**Figure 3.** The leading EOF mode and associated principle component of the number of extreme wet days for each season. Note that the linear trend has been eliminated.

Let us examine in detail the relationship between ENSO and the anomalous NEWD in each season. Considering that the ENSO event matures in winter, we choose the Nino-3 SST anomaly index in winter to represent ENSO and then calculate its lead/lag correlations with anomalous NEWD in China. The left panels of Figure 5 show correlations between the winter Nino-3 index and the anomalous NEWD in China in preceding summer (JJA0) and autumn (SON0), simultaneous winter (DJF0), next spring (MAM+) and summer (JJA+). From Figure 5, we can find the following features. In the preceding summer when an El Niño event is at its onset stage, the NEWD anomaly in China is insignificant; in autumn and winter when the El Niño grows and becomes mature, the NEWD increases obviously in South China but decreases north of Yangtze River; in the following spring when the El Niño is decaying, the NEWD increases mainly in North China, Northeast China and part of Northwest China, but decreases remarkably in Southwest China; then in the following summer, the NEWD increases significantly in the middle reach of Yangtze River, Northeast China and the northern part of Northwest China. The opposite situation is true for a La Niña event. Thus the anomalous patterns of the NEWD during different ENSO phases are extremely different.



(a) (b) (c) (d)

**Figure 4.** Spatial distributions of hetero-correlation fields and corresponding time series for the leading SVD mode between anomalous number of extreme wet days in China and simultaneous SST anomalies in Indo-Pacific oceans in (a) spring, (b) summer, (c) autumn, and (d) winter.

The ENSO affects the extreme precipitation anomaly in China by changing the atmospheric circulation. Similar to those illustrated in the left panels of Figure 5, the right panels of Figure 5 show the lead/lag correlations between the winter Nino-3 index and the 850 hPa wind anomalies, which reflects the anomalous patterns of low-level atmospheric circulation over East Asia corresponding to different phases of an ENSO event. In the developing phase of an El Niño, a cyclonic anomaly in the northeast part of East Asia and an anticyclonic anomaly between Lakes Baikal and Balkhash respectively work together to induce a northerly anomaly east of East Asia. Then, the westerly anomaly east of the Bay of Bengal, together with the northerly anomaly east of East Asia, gives rise to warm and moist airflow from the Bay of Bengal and the Indochina Peninsula to Southwest China and south of South China, leading to excessive rainfall and frequent extreme precipitation events. In the mature phase of an El Niño, a strong anticyclonic anomaly near the Philippines induces a strong southwesterly anomaly along the coast of East Asia. Due to the southwest wind anomaly, the NEWD increases and the extreme precipitation event occurs more frequently in South China. In the decay phase of an El Niño, the anticyclonic wind anomaly over the Philippine Sea tends to be stronger, and the western Pacific subtropical high shifts southward. Thus, the southwest wind anomaly occurs in southeastern China, leading to an increase of the NEWD in Yangtze River valley. The ENSO-related atmospheric circulation anomaly for interpreting the extreme precipitation anomaly in China is similar to that investigated by some previous studies[36, 39, 40] in which a mechanism is proposed to explain how the ENSO event affects the summertime precipitation anomaly in China.

## 5 CONCLUSIONS AND DISCUSSION

The daily precipitation records at 586 stations in China for 1960–2004 are used in this study to investigate the spatio-temporal variation characteristics of the NEWD. For each station and each season, the data of the daily precipitation in all the wet days is ranked in an increasing order, and the thresholds of extreme precipitation are estimated in terms of the 90th percentile. With these thresholds, we calculate the seasonal NEWD and investigate its linear trends, interannual and interdecadal variabilities. Moreover, the relationship between the NEWD anomalies for each season in China and the SST anomalies and associated atmospheric circulation anomalies are also documented. Main conclusions are as follows:

(1) It is more objective to estimate the season-dependent threshold for defining extreme daily precipitation events. Such seasonal thresholds are used to investigate the linear trends of the NEWD in different seasons during the past 45 years. Significant increasing trends of the NEWD are found along the Yangtze River valley only in winter and summer. In North China, the NEWD increases obviously in winter but decreases in summer, whereas, in South China, it increases significantly in spring. There is also an increasing trend of the NEWD in winter, spring and autumn in Northeast China, while a decreasing trend in Northwest China all the year around.

(2) Besides the aforementioned long-term linear trends, the NEWD in China also features obvious interannual and interdecadal variabilities. Typical patterns of the NEWD variabilities without linear trend for different seasons are significantly distinct. In spring and autumn, the patterns are very similar, characterized by a “dipole” mode with opposite phases between northern and southern China; in summer, the pattern appears to be a “tri-pole” mode with opposite phases between Yangtze River valley and southern and northern China; while in winter, it is characterized by a “monopole” mode with the same phase almost everywhere in China but with the anomaly most significant in southern China.

(3) The relation of the NEWD anomalies in China to the SST anomalies in Indo-Pacific Oceans is primarily associated with ENSO. The anomalous patterns of the NEWD during different ENSO phases are extremely different. In the preceding summer when an El Niño event is at its onset stage, the NEWD anomaly in China is insignificant; in autumn and winter when the El Niño grows and becomes mature, the NEWD increases obviously in South China but decreases north of Yangtze River; in the following spring when the El Niño is decaying, the NEWD increases mainly in North China, Northeast China and part of Northwest China, but decreases remarkably in Southwest China; then in the following summer, the NEWD increases significantly in the middle reach of Yangtze River, Northeast China and the northern part of Northwest China. The opposite situation is true for a La Niña event.

(4) The ENSO affects the extreme precipitation anomaly in China by changing the atmospheric circulation. In the developing phase of an El Niño, the westerly anomaly east of the Bay of Bengal, together with the northerly anomaly in the east of East Asia, gives rise to warm and moist airflow from the Bay of Bengal and the Indochina Peninsula to Southwest China and south of South China, leading to excessive rainfall and frequent extreme precipitation events. In the mature phase of an El Niño, a strong anticyclonic anomaly near the Philippines induces a strong southwesterly anomaly along the coast of East Asia, inducing more frequent extreme precipitation in South China. In the decay phase of an El Niño, the anticyclonic wind anomaly over the Philippine Sea and the southward-shifted western Pacific subtropical high jointly cause a southwest wind anomaly in southeastern China, leading to the increase of extreme precipitation in Yangtze River valley.

It should be noted that this analysis only investigates principal features of spatial and temporal variations of frequency of the extreme daily precipitation events in China. The causes of these variations are not explored thoroughly. Specially, as shown in this analysis, the NEWD during wintertime increases nearly in the whole of China. Is such a phenomenon related to the global warming? Besides, we do see an increasing trend of the summertime NEWD along Yangtze River valley, but a decreasing trend since the 21st century. What will be the trend in the future? How do the SST anomalies change the atmospheric circulation and further affect the extreme precipitation in China? All of these questions are deserved to be answered in future studies.

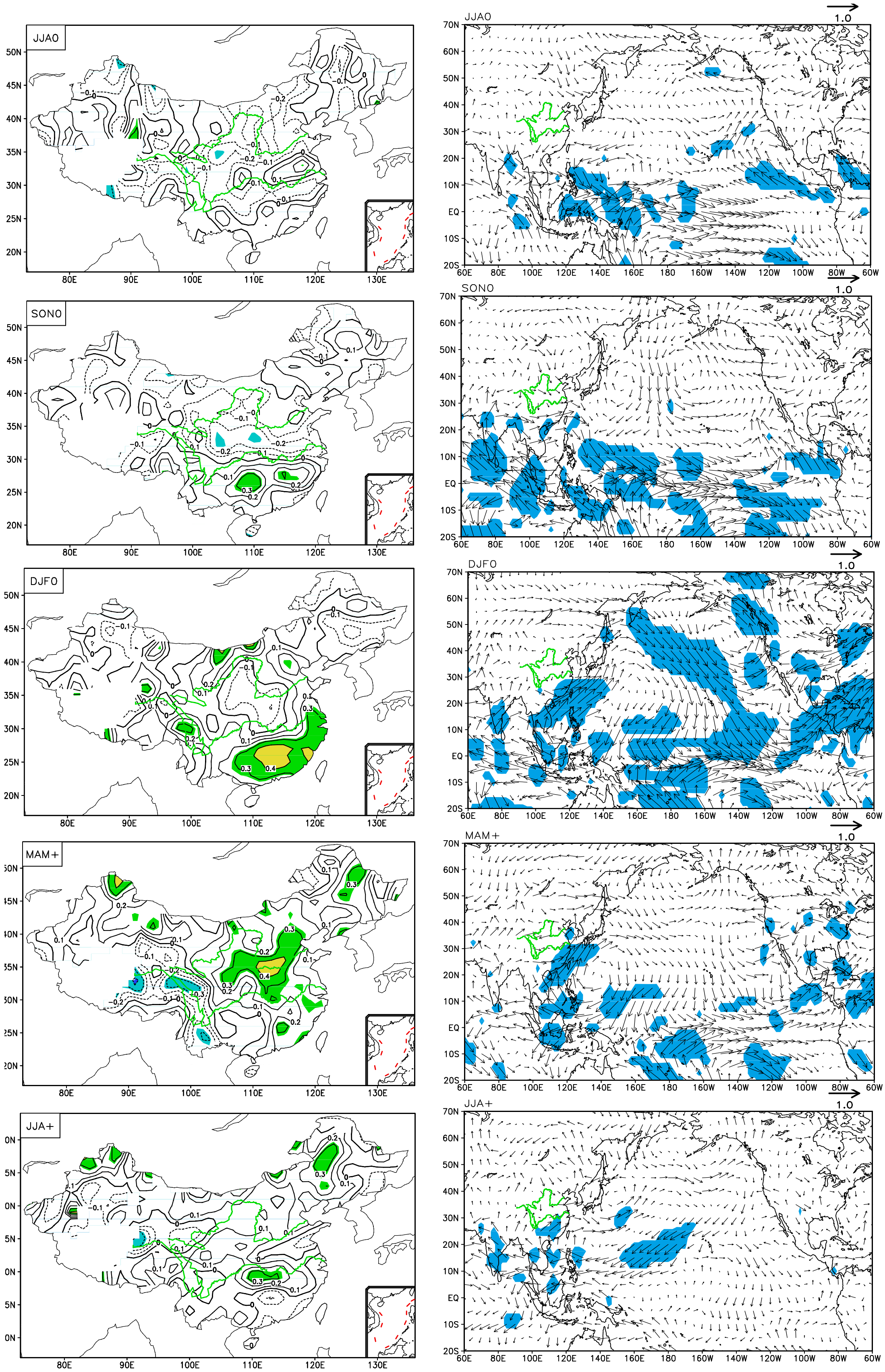



**Figure 5.** Correlations of the winter Nino-3 SST anomaly index with the anomalous number of extreme wet days in China (left panels) and with the 850 hPa wind anomalies (right panels) in preceding summer (JJA0) and autumn (SON0), simultaneous winter (DJF0), next spring (MAM+) and summer (JJA+). Note that the regions with significance exceeding 95% are shaded.

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