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Trend of extreme precipitation events over China in last 40 years*

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Using the daily precipitation data of 740 stations in China from 1960 to 2000, the analysis on the variations and distributions of the frequency and the percentage of extreme precipitation to the annual rainfall have been performed in this paper. Results indicate that the percentage of heavy rains (above 25mm/day) in the annual rainfall has increased, while on average the day number of heavy rains has slightly reduced during the past 40 years. In the end of 1970s and the beginning of 1980s, both the number of days with extreme precipitation and the percentage of extreme precipitation abruptly changed over China, especially in the northern China. By moving t test, the abrupt change year of extreme precipitation for each station and its spatial distribution over the whole country are also obtained. The abrupt change years concentrated in 1978–1982 for most regions of northern China while occurred at various stations in southern China in greatly different/diverse years. Besides the abrupt change years of extreme precipitation at part stations of Northwest China happened about 5 years later in comparison with that of the country's average.

Keywords: extreme precipitation events, frequency, abrupt change, extreme events
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1. Introduction

Recently, under the background of global warming the variation of extreme values and extreme events has received wide attention. Past researches on climate change mainly focused on the average value of climate variable; however, changes in the frequency or intensity of extreme events are more likely to have profound impacts on both human society and natural environment. The report of the Intergovernmental Panel on Climate Change (IPCC) raised the question: has the climate become more variable or extreme?

The IPCC report (2007) points out that[1] on the global scale no evidence is found that extreme weather events, or climate variability, has distinctively increased, however on the regional scale there is clear evidence of changes in some extremes and climate variability indicators. For example, in many areas data analysis indicates that the magnitude of extreme precipitation has increased while the counterpart of extreme temperature also changed. Climate model outputs have projected that with global warming extreme events will change in the future, such as the increase in extreme high temperatures, decrease in extreme low temperatures, and increase in intense precipitation events.[2] In the past several decades the frequency of extreme cold events and frost days in North America has decreased,[3] while extreme heavy rainfall events has somewhat increased in the USA, China, Australia, Canada, Norway and Mexico.[4]

Shi *et al*[5] found that in the last 50 years extreme heavy rains have decreased in North China while they have increased in Northwest China. Wei[6] studied the relationship between abnormal changes of summer precipitation in the middle and lower reaches of Yangtze River and the decadal scale factors as well as inter-annual scale air and sea factors, etc. Great progress has been achieved in the research on the process and mechanism of the climate system through nonlinear dynamics,[7−22] however with the background of global warming the extreme climate events are likely to become more changeable and complicated. Research of China's precipitation extremes is far from enough, and has not yet given a clear view of

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how the frequency and trend of precipitation extremes change under the background of global warming.

In this paper we use both classic and nonparametric statistic methods to analyse the daily precipitation of China during the past 40 years and obtains the temporal variation and spatial distribution of extreme precipitation. Furthermore we also want to obtain the distribution of the abrupt change year of precipitation extremes frequency over China.

2. Methodology

In China if the volume of daily precipitation exceeds the threshold of 50 mm/25 mm, it is usually defined as a torrential rain/ heavy rain, respectively. The patterns of climate have large spatial variability across the country, fixed/uniform thresholds for extreme precipitation are not suitable for the whole country where climate differs quite a lot from one area to another, therefore, the selection of appropriate thresholds or indicators for extreme precipitation is very important.[23] In this paper the thresholds of extreme precipitation events are defined at each station based on the actual daily precipitation data as in the following.

Usually, the definition of extreme events can be divided into two categories: one is parametric (or fixed) threshold (PT) method, and the other is nonparametric threshold (NPT) method. In observational data analysis the one mostly used is the gamma distribution function method.[24] Bonsal *et al*[23] pointed out that if the length of a climatic time series is n, and $x_1, x_2, \cdots, x_m, \cdots, x_n$ are arranged in an ascending order, then the probability of some value less than or equal to x_m is

$$P = (m - 0.31) / (n + 0.38), \tag{1}$$

where m is the sequence number of x_m. If the length of a sequence n is 30, then the value of 95th percentile is obtained by linear interpolation of x_{29} ($p = 94.4\%$) and x_{30} ($p = 97.7\%$).

Here the 30 year average of the 95th percentile of yearly daily precipitation series at a station for 1961 through 1990 is defined as the threshold of extreme precipitation for the station, e.g. if one day's precipitation exceeds this threshold, the precipitation is defined as an extreme precipitation event. Using formula (1) to compute the approximate value of percentile is not only for the convenience but also for avoiding any assumption of the probability distribution of the time series analysed. Comparing this method with the gamma distribution method indicates that the results are almost the same.

Moreover, in order to study the variation trend of precipitation extremes quantitatively, the extreme index γ is introduced, which is defined as the ratio of days of extreme precipitation to the total number of precipitation days, expressed in percentage

$$\gamma = \frac{\text{days of extreme precipitation}}{\text{total number of precipitation days}} \times 100\%. \tag{2}$$

3. Analysis of the results

The daily rainfall data collected at 740 stations over China in the period of 1960–2000 published by the National Climate Centre (CMA) are used in this paper. In order to realistically reflect the spatial-temporal distributions of precipitation, the data are first checked station by station, and year by year; the data at 435 stations satisfy the requirement of continuity, and therefore used in the following.

3.1. The variation and distribution of extreme precipitation events determined by the PT method

In the past 40 years, it has been observed that the yearly number of heavy rain days averaged over China was 8, and the number of days showed no significantly temporal change (Fig.1(a)). Figure 1(b) shows the change of the percentage of the annual days of heavy rains relative to the annual total precipitation days averaged over the whole country (i.e. γ), the variation lying between 6.2%–7%. It can be seen from Figs.1(a) and 1(b) that in the last four decades of 20th century, although the annual average number of days with heavy rains somewhat increased, γ has decreased only slightly. The research by Ren *et al*[25] shows that in the past 50 years no obvious change has been found in the annual average volume of precipitation over China; our results basically show the same tendency.

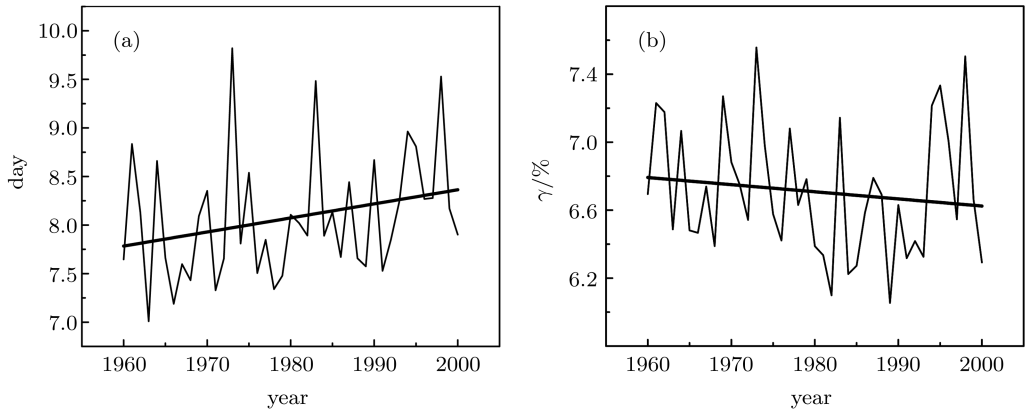


Fig.1. Yearly variations of the day number of heavy rains (over 25mm/day) averaged over China (a) and its percentage to the total day number of precipitation (b) (The thick line is the linear fit).

Viewed from the angle of spatial distribution, the extreme index of precipitation γ has decreased by 5%–10% in most areas of North China and Northeast China in the last 40 years, but evidently increased in the middle and lower reaches of Yangtze River and the coastal regions of southeast China. Moreover, the extreme index γ has also slightly increased in the Hexi Corridor and some regions of Northwest China (Fig.2). Zhai *et al*[26] concluded that in the last 45 years the number of days with precipitation more than 50 and 100 mm per year has decreased. If the threshold is set at 25 mm (heavy rain), in most parts of northern China, including North China and Northeast China, the number of days with extreme precipitation per year are still decreasing, and this trend to some extent corresponds to the drought process in this region. In the meantime, the increase in extreme precipitation in the middle and lower reaches of Yangtze River and the coastal regions of Southeast China, which are mainly affected by the East Asian Summer Monsoon and Typhoons, might be the main reason for the increase in γ in these regions.

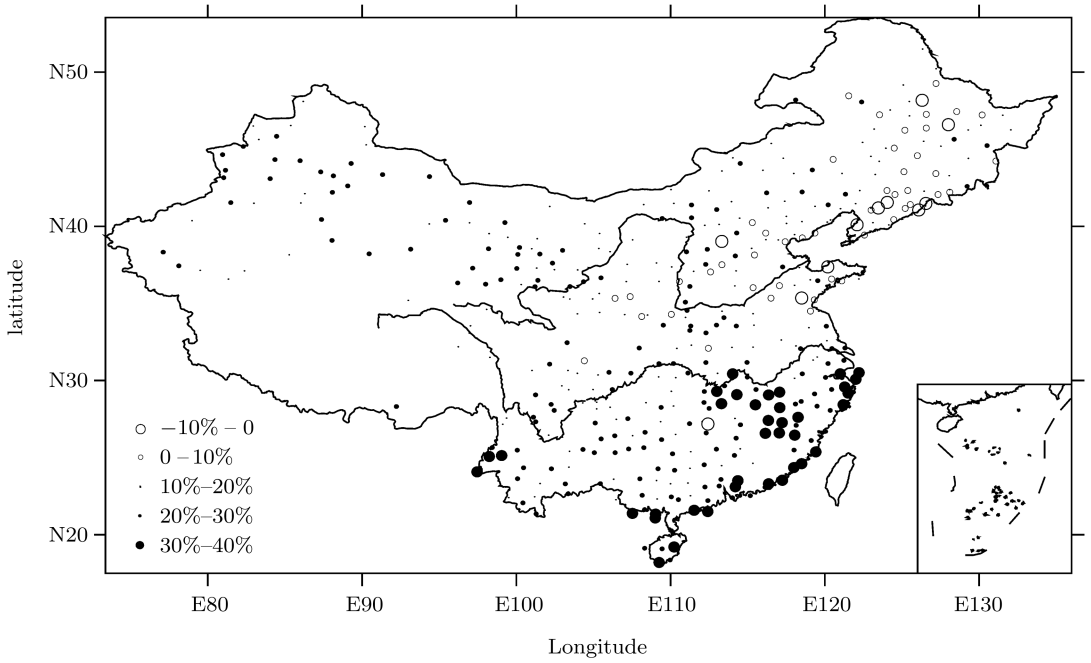


Fig.2. Geographic distribution of the total change of γ in China over 1960–2000 determined by the PT method.

3.2. The variation and distribution of extreme precipitation events determined by the NPT method

Figure 3(a) shows the temporal evolution of the day number of extreme precipitation (95th percentile) averaged over China and its percentage determined by the NPT method. If the threshold of extremes is set at the 99th percentile, the average day number of extreme precipitation is less than 4 days/year, however, when the threshold is set at the 95th percentile, this number increases to more than 12 days/year. Since the probability density distribution of precipitation time series is not Gaussian, in order to avoid pitfalls the threshold of extreme precipitation is set at the average of yearly daily precipitation series at the 95th percentile over the period of 1960–2000. By doing so, the results are more reliable in comparison with those defined by the 99th percentile due to the enough length of data. Results obtained indicate that in the late 1970s and the beginning of 1980s, the average number of days with extreme precipitation changed abruptly from about 14 days to 20 days in 1979.

Figure 3(b) gives the temporal evolution of the extreme index γ, which reflects the extreme trend of precipitation in China. It is observed from Fig.3(b) that extreme index γ is approximately 16% before 1979 and it has exceeded 20% after 1979. This indicates that an abrupt change did exist in both the frequency and extent of extreme precipitation in the late 1970s and the beginning of 1980s.

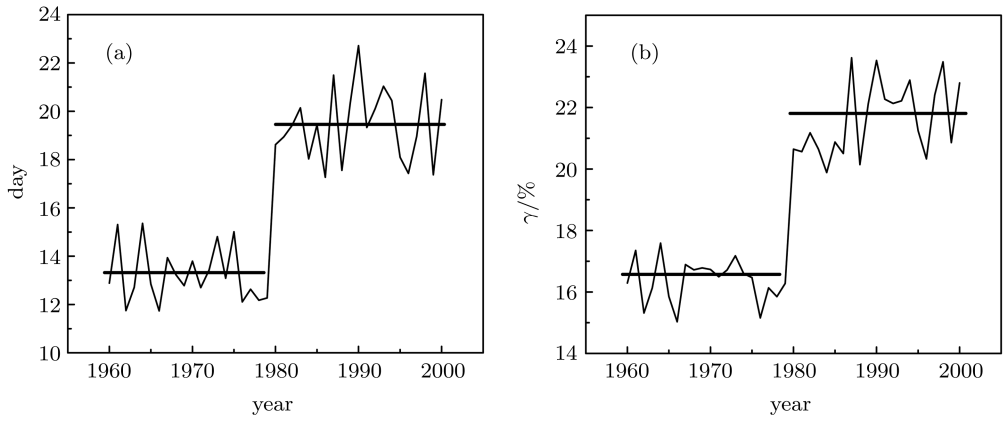


Fig.3. Yearly variations of the number of extreme precipitation days (at 95th percentile) averaged over China (a) and its percentage of the total number of precipitation days (b) (The thick line denotes the mean values of sub-series before and after 1979).

From Fig.4 we can conclude that northern China (including North China, Northeast China and Northwest China) is the regions where the extreme trend of precipitation was evident, and it was even more significant in the Hexi Corridor, the northwest part of Tibetan Plateau and part of Northwest China. Whether or not this extreme trend of precipitation is related with the drought process of northern China since the 1980s is the problem to be resolved in further research. Meanwhile, no obvious trend can be found in the precipitation over southern China.

3.3. The distribution of abrupt change years

As is known from the above, an abrupt change happened in both the frequency and magnitude of extreme precipitation over China in the late 1970s and beginning of 1980s (Figs.3(a) and 3(b)). In the following, the moving t test technique is used to determine the year when the abrupt change occurred at each station, and give the distribution of abrupt change year over the whole country.

The moving t test can be used to detect abrupt change point, and it is briefly introduced as follows:

A continuous random variable x series with length n is at first divided into two sample subsets: x_1 and x_2; and μ_i, S_i^2 and n_i are the mean value, sample variance and length of x_i, $(i = 1, 2)$ respectively. Thus there always exists one sample (corresponding to a certain year) between the two sample subsets and the final result we obtain is the notability test of average before and after this year.

Original assumption $H_0 : \mu_1 - \mu_2 = 0$, i.e. there is no difference between x_1 and x_2. Define t statistic as

$$t_0 = \frac{\bar{x}_2 - \bar{x}_1}{S_P \left(\frac{1}{n_1} + \frac{1}{n_2} \right)^{1/2}}, \tag{3}$$

where S_P is the joint variance, and $S_P^2 = \dfrac{(n_1-1)S_1^2+(n_2-1)S_2^2}{n_1+n_2-2}$ is the unbiased estimation of σ^2. Clearly, we have $t_0 \sim t(n_1+n_2-2)$ distribution, given the confidence level α, and thus obtain the critical value t_α. Compute t_0 and then compare t_0 with t_α under H_0. If $|t_0| \geq t_\alpha$, the assumption H_0 is denied, e.g. the difference is significant; and if $|t_0| \leq t_\alpha$, original assumption H_0 is acceptable.

Using this method to test one time series, we obtain its corresponding t_0 test series; in those years in which we have $|t_0| \geq t_\alpha$, the year corresponding to the peak/valley value of t_0 is usually called the abrupt change year (or abrupt change point) and the difference in precipitation between the years immediately before and after is the biggest.

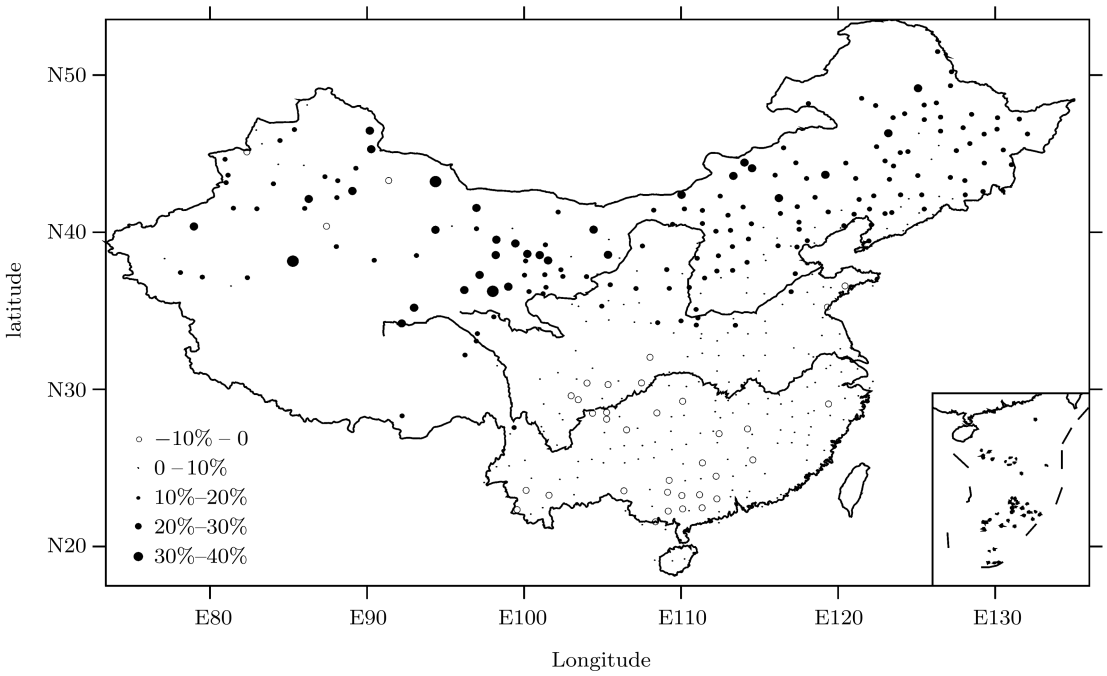


Fig.4. The same as Fig.2 but determined by the NPT method.

In order to analyse the decadal abrupt change, set $n_1 = n_2 = 10$ and $\alpha = 0.01$, correspondingly $t_\alpha = t_{0.01} = 2.88$. Figures 5(a) and 5(b) are the average number of days with extreme precipitation events per year and its t_0 test series respectively. From Fig.5(b) we can conclude that the abrupt change points ($|t_0| \geq t_\alpha$) are 1978, 1979, 1980, 1981, 1982, and 1983. For the sake of convenience, the peak value year of t_0, e.g. 1979, is selected as the abrupt change year. Later, we will apply this method to all 435 stations and obtain the distribution of the abrupt change years (Fig.6).

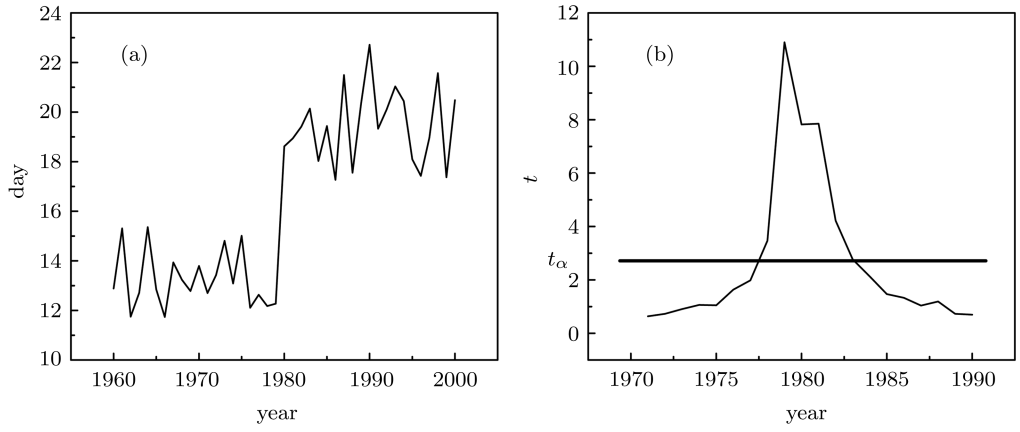


Fig.5. Yearly days of extreme precipitation (95th percentile) averaged over China (a) and its t statistic series (b), with t_α = average t.

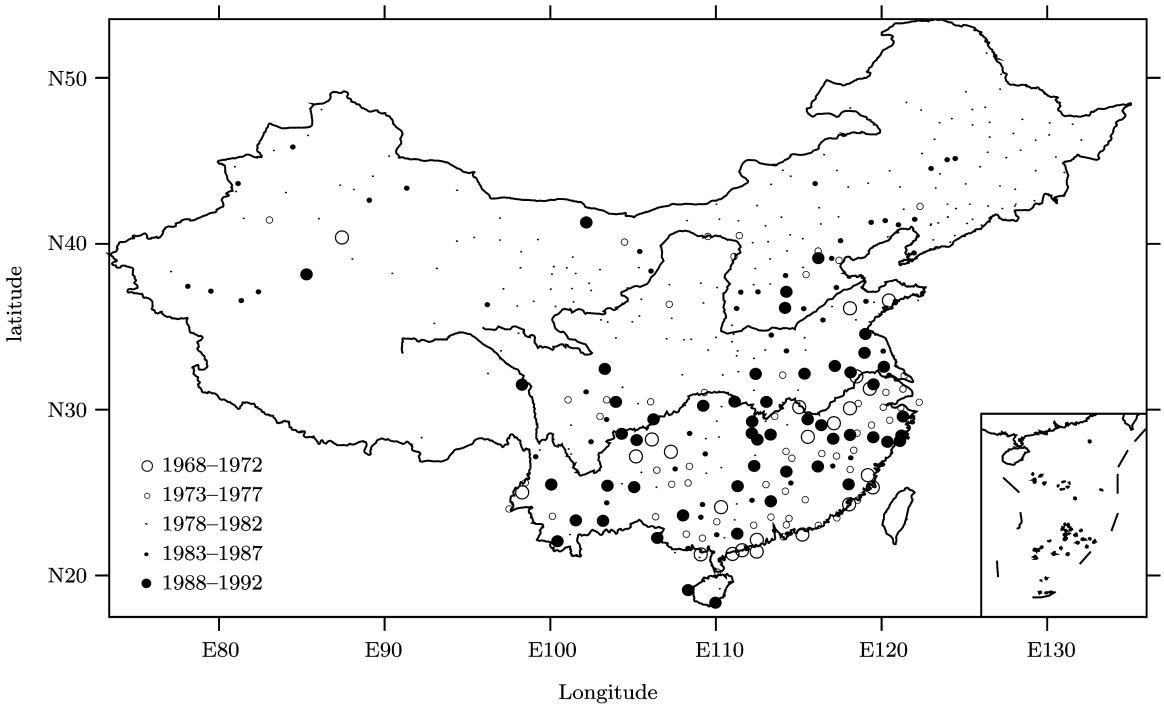


Fig.6. Geographic distribution of the abrupt change years of the yearly number of extreme precipitation days (at 95th percentile).

The abrupt change years concentrates mostly in the period of 1978–1982 in North China and Northeast China, but they show no significant characteristic of overall distribution in southern China. The confidence level tests suggest that there are more than one hundred stations where the confidence level α is less than 0.1, and these stations are mostly located in North China. Generally speaking, the abrupt change years come later than the average over the whole country in the middle and lower reach of Yangtze River, but 10 years earlier than the average in South China and part of the Yunnan–Guizhou Plateau (Fig.6). In most parts of Northwest China the abrupt change years are about 5–10 years later than the average over the whole country, which is in good agreement with the conclusion about the abrupt change years of this region obtained by Yu *et al.*[27]

4. Conclusions

Using two different kinds of extreme event threshold definitions: parametric and nonparametric methods, the temporal trend and spatial distribution of the frequency of extreme precipitation and its percentage of the annual rainfall have been calculated and analysed, and the spatiotemporal distribution of the decadal abrupt change of extreme precipitation events in the late 1970s and the beginning of the 1980s has also been analysed. Conclusions are summarized as follows:

1. In the past 40 years, there have been 8 days of heavy rain every year as averaged over the whole country when the daily precipitation exceeded 25 mm, and generally, the number of heavy rain days showed no significant change. In the past four decades, although the number of heavy rain days per year has somewhat increased, its percentage relative to the total number of precipitation days per year has only slightly decreased. The regions where the extreme index γ has evidently increased concentrates in the middle and lower reaches of Yangtze River and the coastal regions of southeast China, while γ showed no significant change in most areas of northern China.

2. An abrupt change happened in both the frequency of extreme precipitation and the extreme index γ in the late 1970s and the beginning of the 1980s. Before 1979 the number of extreme precipitation days per year averaged over the whole country was about 14, and after this abrupt change it has increased to approximately 20. Also, before 1979 the extreme index γ was approximately 16% and after 1979 the percentage has exceeded 20%.

3. The study of the abrupt change of extreme precipitation happened around the late 1970s and the

beginning of the 1980s, shows that the abrupt change years differ greatly in different regions. The abrupt change years concentrates mostly in the period of 1978–1982 in North China and Northeast China, but they show no significant variation of overall distribution in southern China. In general, the abrupt change years of the middle and lower reaches of Yangtze River come later than that of the average over the whole country, but can be 10 years earlier than that of the average in South China and part of the Yunnan–Guizhou Plateau. In most parts of Northwest China the abrupt change years are about 5–10 years later than that of the average over the whole country, which is in good agreement with the conclusion about the abrupt change years for this region obtained by Yu *et al.*[27]

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