Changes of Precipitation Intensity Spectra in Different Regions of Mainland China During 1961–2006

JIANG Zhihong[1*] (江志红), SHEN Yuchen[1] (沈雨辰), MA Tingting[1] (马婷婷), ZHAI Panmao[1,2] (翟盘茂), and FANG Sida[1,3] (方思达)

1 *Collaborative Innovation Center on Forecast and Evaluation of Meteorological Disasters, Key Laboratory of Meteorological Disaster of Ministry of Education，Nanjing University of Information Science & Technology, Nanjing* 210044

2 *Chinese Academy of Meteorological Sciences, Beijing* 100081

3 *Wuhan Regional Climate Center, Wuhan* 430074

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ABSTRACT

The spectral characteristics of precipitation intensity during warm and cold years are compared in six regions of China based on precipitation data at 404 meteorological stations during 1961–2006. In all of the studied regions except North China, with the increasing temperature, a decreasing trend is observed in light precipitation and the number of light precipitation days, while an increasing trend appears in heavy precipitation and the heavy precipitation days. Although changes in precipitation days in North China are similar to the changes in the other five regions, heavy precipitation decreases with the increasing temperature in this region. These results indicate that in most parts of China, the amount of precipitation and number of precipitation days have shifted towards heavy precipitation under the background of a warming climate; however, the responses of precipitation distributions to global warming differ from place to place. The number of light precipitation days decreases in the warm and humid regions of China (Jianghuai region, South China, and Southwest China), while the increasing amplitude of heavy precipitation and the number of heavy precipitation days are greater in the warm and humid regions of China than that in the northern regions (North China, Northwest China, and Northeast China). In addition, changes are much more obvious in winter than in summer, indicating that the changes in the precipitation frequency are more affected by the increasing temperature during winter than summer. The shape and scale parameters of the Γ distribution of daily precipitation at most stations of China have increased under the background of global warming. The scale parameter changes are smaller than the shape parameter changes in all regions except Northwest China. This suggests that daily precipitation shifts toward heavy precipitation in China under the warming climate. The number of extreme precipitation events increases slightly, indicating that changes in the Γ distribution fitting parameters reflect changes in the regional precipitation distribution structure.

Key words: precipitation intensity distribution, different regions, Γ distribution

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1. Introduction

Changes in amount, frequency, and intensity of precipitation under the background of global warming have caused widespread concern. Many studies indicated that the frequency and intensity of heavy precipitation events have increased in the past 30 years (Groisman et al., 1999; Alpert et al., 2002; Haylock and Goodess, 2004; Donat et al., 2013), and so is the dry spells with higher frequency and intensity, and longer duration, especially in the tropical and subtropical regions (Easterling et al., 2000; Groisman and Knight, 2008). Changes of precipitation intensity, frequency, and amount in China are also investigated by many

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*Corresponding author: zhjiang@nuist.com.

researchers (Gong and Wang, 1999; Zhai et al., 1999, 2005, 2007; Yan and Yang, 2000; Ma et al., 2003, 2005; Dai et al., 2004; Jiang et al., 2007; Qian et al., 2007; Wang and Zhai, 2008). Their studies indicate an increasing trend in extreme precipitation and a decreasing trend in light precipitation in most regions of China, and changes of precipitation intensity vary among different regions.

Recently, Wu and Fu (2013) investigated the changes of precipitation spectrum on different spatial scales and found a quasi-linear relationship between global temperature and precipitation. Wu and Fu (2013) also indicated that different precipitation intensities respond differently to temperature increase although all regions show a spectral shift from light precipitation to heavy precipitation. Overall, the precipitation spectral changes in different regions of China under the increasing temperature are similar to the observed global changes. However, non-homogeneous land surface coverage and topography can change the local energy, momentum, and water flux, as well as the water vapor transport among regions. Thus, regional precipitation changes are associated with great uncertainty. Clearly, further research about the changes in the distribution of precipitation intensity and its regional differences is required to determine the response of China's precipitation to increasing temperature.

Statistically, climatic variables can be regarded as random variables, and changes in the precipitation intensity spectrum can be reflected by changes in the probability distribution pattern. The Γ distribution is one of the most commonly used models to describe the probability distribution of precipitation (Yao and Ding, 1990; Wilks, 1995). The probability density function depends on the shape (α) and scale (β) parameters of the Γ distribution function. Studying changes in the Γ distribution function parameters can improve our understanding of changes in the distribution of precipitation intensity and provide a basis for estimating future changes in the precipitation intensity spectra with global warming. Therefore, we use the complete daily precipitation data at 404 meteorological stations 1) to study the spectral structure of precipitation intensity in six different regions of China (Northwest China, Northeast China, North China, South China, Southwest China, and the Jianghuai region), 2) to compare the spatiotemporal differences of precipitation intensity between different regions under a colder and warmer climate, and to reflect possible changes of the spectral structure of precipitation under global warming. In addition, the Γ distribution is used to fit the daily precipitation distribution, to investigate the connection between changes in precipitation intensity spectra and changes in probability distribution function parameters, and eventually to improve our overall understanding of precipitation changes in various regions of China under the changing climate.

2. Data and methods

2.1 Data

The observation data used in the present study were obtained from the Information Meteorological Center, China Meteorological Administration. Daily precipitation data (1961–2006) cover 404 meteorological stations in six regions of China, including Northwest China (north of 36°N, west of 110°E), Northeast China (42°–52°N, 115°–135°E), North China (35°–42°N, 110°–120°E), the Jianghuai region (28°–34°N, east of 110°E), South China (Fujian, Guangdong, Guangxi, and Hainan), and Southwest China (south of 29°N, 97°–104°E). The distribution of 404 stations is shown in Fig. 1. Table 1 contains the basic information for each study region, including the average annual precipitation and number of days of precipitation.

The global temperature data include the mean global temperature anomaly data (1961–2006) that are provided by NOAA (http://www.ncdc.noaa.gov/oa/ncdc.html).

2.2 Methods

2.2.1 Determining daily precipitation level thresholds

To account for the regional differences and non-uniform precipitation, the multi-year precipitation data from each station that are greater than or equal to 0.1 mm are sorted in ascending order. In addition, precipitation intensity of each percentile is determined by using the threshold method proposed by Bonsal

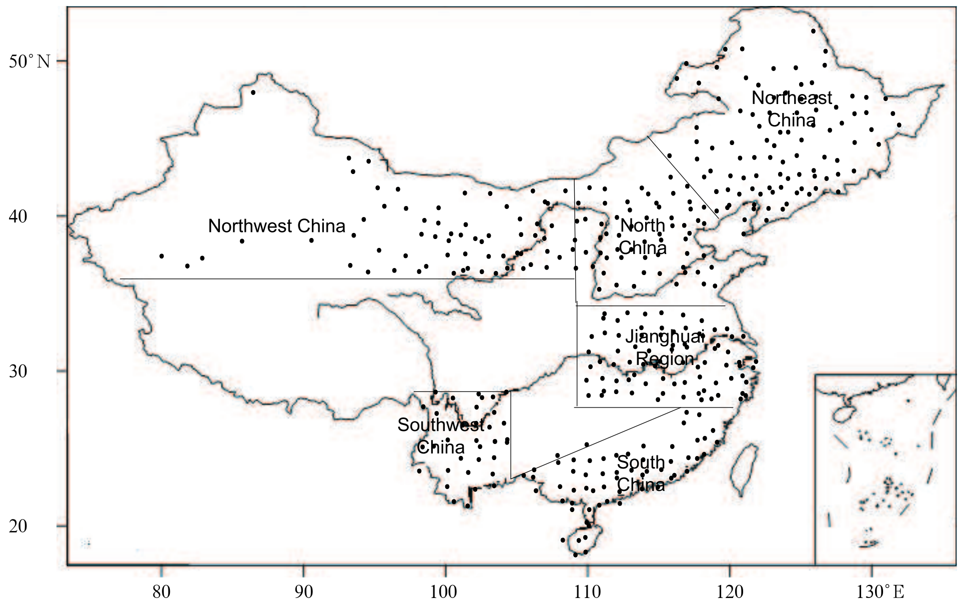

Fig. 1. Distribution of the meteorological stations in six regions of China.

Table 1. Basic information for the meteorological stations in each region

Study region	Number of stations	Total annual precipitation (mm)	Average annual precipitation frequency (day)	Daily precipitation at specified precipitation intensity (mm day^{-1})					
				20%	30%	60%	70%	80%	90%
Northwest China	70	193.6	55	0.3	1.9	2.5	3.0	4.8	8.5
Northeast China	95	543.1	97	0.3	2.9	3.8	4.8	8.2	15.6
North China	57	530.5	78	0.4	3.5	4.6	5.8	9.9	18.7
Jianghuai region	80	1258.7	137	0.4	5.3	6.8	8.4	13.6	24.1
Southwest China	62	1632.5	150	0.4	5.5	7.3	9.3	15.9	29.7
South China	40	1092.9	141	0.4	4.2	5.4	6.7	10.9	19.2

et al. (2001). In the present paper, daily precipitation intensities are divided into 12 levels, i.e., 0–10%, 10%–20%, ..., 90%–95%, 95%–99%, and 99%–100%. Precipitation intensity below 10% is defined as extremely light precipitation, and precipitation intensity above 95% is defined as extremely heavy precipitation.

2.2.2 Calculating the contribution rates of different precipitation intensities

To compare the precipitation spectra of various regions, we calculate the percentage of the number of different precipitation intensity days relative to the total number of precipitation days; this percentage is known as the contribution rate of the number of days for a specific precipitation intensity. The percentage of the total amount of precipitation at the specific precipitation intensity relative to the total amount of precipitation is referred to as the contribution rate of that specific precipitation intensity.

When calculating the contribution rates of the number of different precipitation intensity days and the rates of precipitation intensity for each region, the arithmetic means of the contribution rates of each site are used. The differences between the precipitation contribution rates of different stations are reflected by the value that is twice the standard deviation of the stations in each region.

2.2.3 Selecting cold and warm years and verifying the precipitation variation

Liu et al. (2009) showed that changes in the spectral structure of regional precipitation intensity are closely related to the global mean temperature. Therefore, to investigate the impacts of global warming on the spectral structure of the regional precipitation intensity distribution, five of the coldest and warmest years from 1961–2006 were selected according to the mean global temperature anomaly sequence for the composite analysis. The five coldest years are 1964, 1976, 1974, 1965, and 1971, and the five warmest years are 2005, 1998, 2003, 2002, and 2006. The warmest years occurred after the 1990s, and the coldest years occurred during the 1960s and 1970s.

In this paper, the F-test is used to examine the significance of the differences of contribution rates of the precipitation (the number of precipitation days) for different precipitation intensities between warm and cold years (Wei, 2007).

2.2.4 Fitting of the Γ *distribution and estimating the related parameters*

The probability density function of the Γ distribution is determined as:

$$f(x)=\frac{1}{\beta^{\alpha}\Gamma(\alpha)}x^{\alpha-1}\exp(-\frac{x}{\beta}),\quad x\geqslant 0.$$

The distribution function is defined as:

$$F(x)=\frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_{0}^{x}x^{\alpha-1}\exp(-\frac{x}{\beta})\mathrm{d}x,\quad x\geqslant 0,$$

where α is shape parameter, and β is scale parameter. Note that $\alpha>0$ and $\beta>0$ always hold. The smaller α is, the more skewed the Γ distribution is, and the smaller the average daily precipitation intensity will be. Given $\beta=\sigma C_S/2=\sigma/\sqrt{\alpha}$, if α is constant, the value of β depends on the mean square error of the sequence. Smaller values of β correspond to less dispersed Γ distributions (Yao and Ding, 1990; Zhang and Ding, 1991).

The robust L-estimator (Yao and Ding, 1990; Cai et al., 2007) is used to estimate the Γ distribution parameters, and the Kolmogorov-Smirnov (K-S) test is used to examine the fitness of the Γ distribution.

3. Comparison of precipitation spectral characteristics between cold and warm years in different regions

3.1 Precipitation spectral characteristics

The total annual precipitation, annual number of precipitation days, average daily precipitation intensity, and percentiles of differences between warm and cold years relative to the climatology in different regions of China are shown in Fig. 2. In North and Southwest China, the total annual precipitation is lower during warm years than cold years. However, in the Jianghuai region and South China, the total annual precipitation is greater during warm years than cold years. Both of these differences are significant at the 95% confidence level. Furthermore, the annual numbers of precipitation days in North China, the Jianghuai region, South China, and Southwest China are greater during cold years than warm years. Besides, the relative differences of the annual numbers of precipitation days in these regions are greater than 14% (Fig. 2d). All six regions have greater average daily precipitation intensities during warm years. The difference is greater than 11% between cold and warm years in the Jianghuai region, North China, South China, and Southwest China (at a 95% confidence level). Thus, the precipitation in various regions of China is characterized by decreasing average precipitation days and increasing precipitation intensity, with increasing temperature. In addition, except North China and Southwest China, there is an increasing trend of the average annual precipitation in Northwest China, Northeast China, the Jianghuai region, and South China.

3.2 Contribution rates of precipitation days and amount at different intensity levels

3.2.1 Precipitation days

To investigate the changes in precipitation in different regions at different intensity levels under global warming, Fig. 3 shows a comparison of the contribution rates of precipitation days in various regions of China between the typical warm and cold years. In North China, Northwest China, Southwest China, Northeast China, the Jianghuai region, and South China, the contribution rates of light precipitation days are smaller during warm years than cold years. However, the contribution rates of heavy precipitation days are greater during warm years than cold years, with the different turning threshold generally occurring at an intensity of 20%–30%. The number of light precipitation days at the intensity less than 20%–30% significantly decreases during warm years. For precipitation with intensity greater than 20%–30%, the number of precipitation days during warm years increases with increasing precipitation intensity. In general, the differences in the amount of precipitation between cold

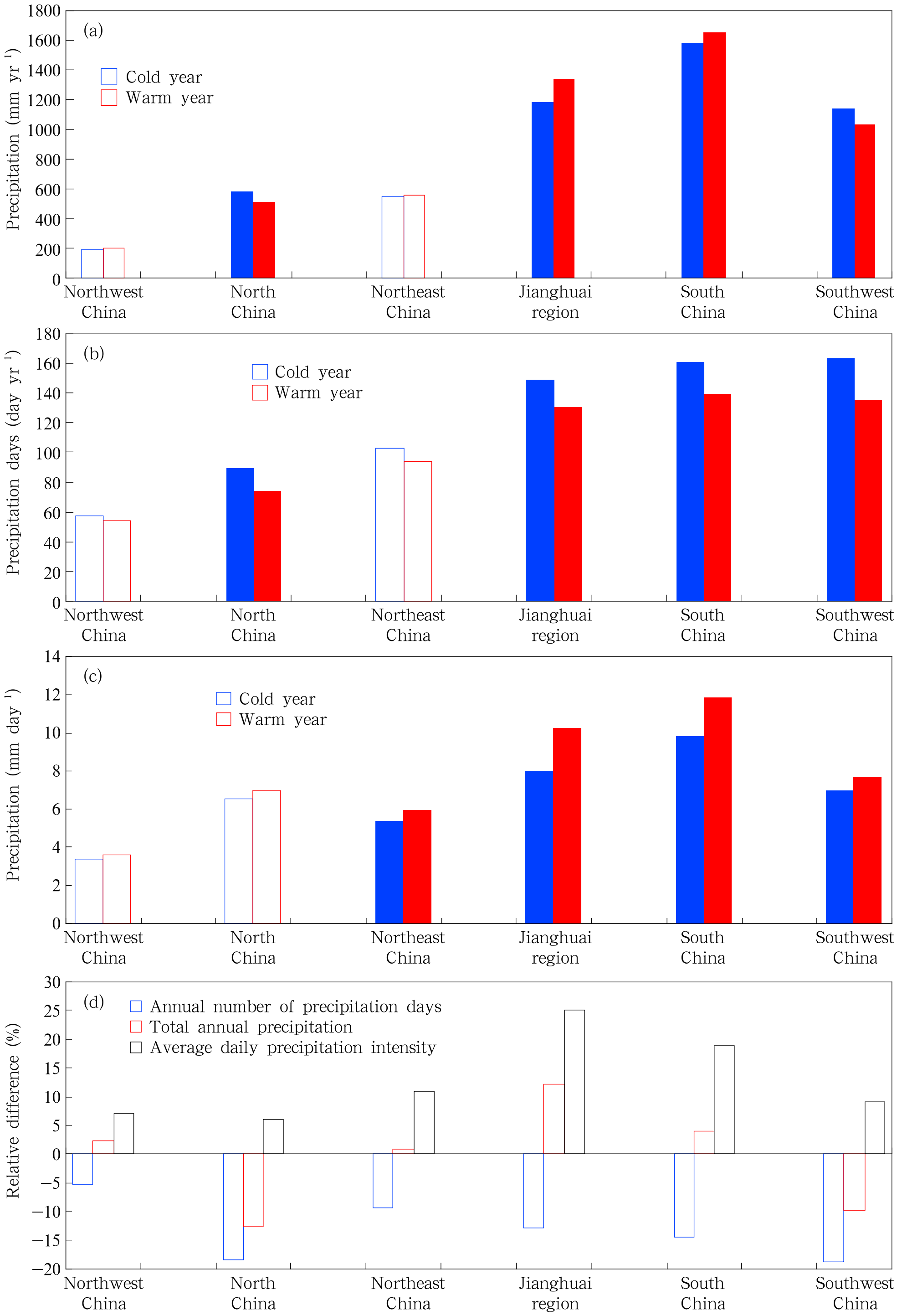

Fig. 2. Basic characteristics of precipitation for the six regions of China during typical warm and cold years. (a) Total annual precipitation, (b) annual number of precipitation days, (c) average daily precipitation, and (d) relative difference of the amounts of precipitation between cold and warm years. The relative difference is the percentage of the difference between cold and warm years relative to the annual average, and the shaded areas indicate a 95% confidence level.

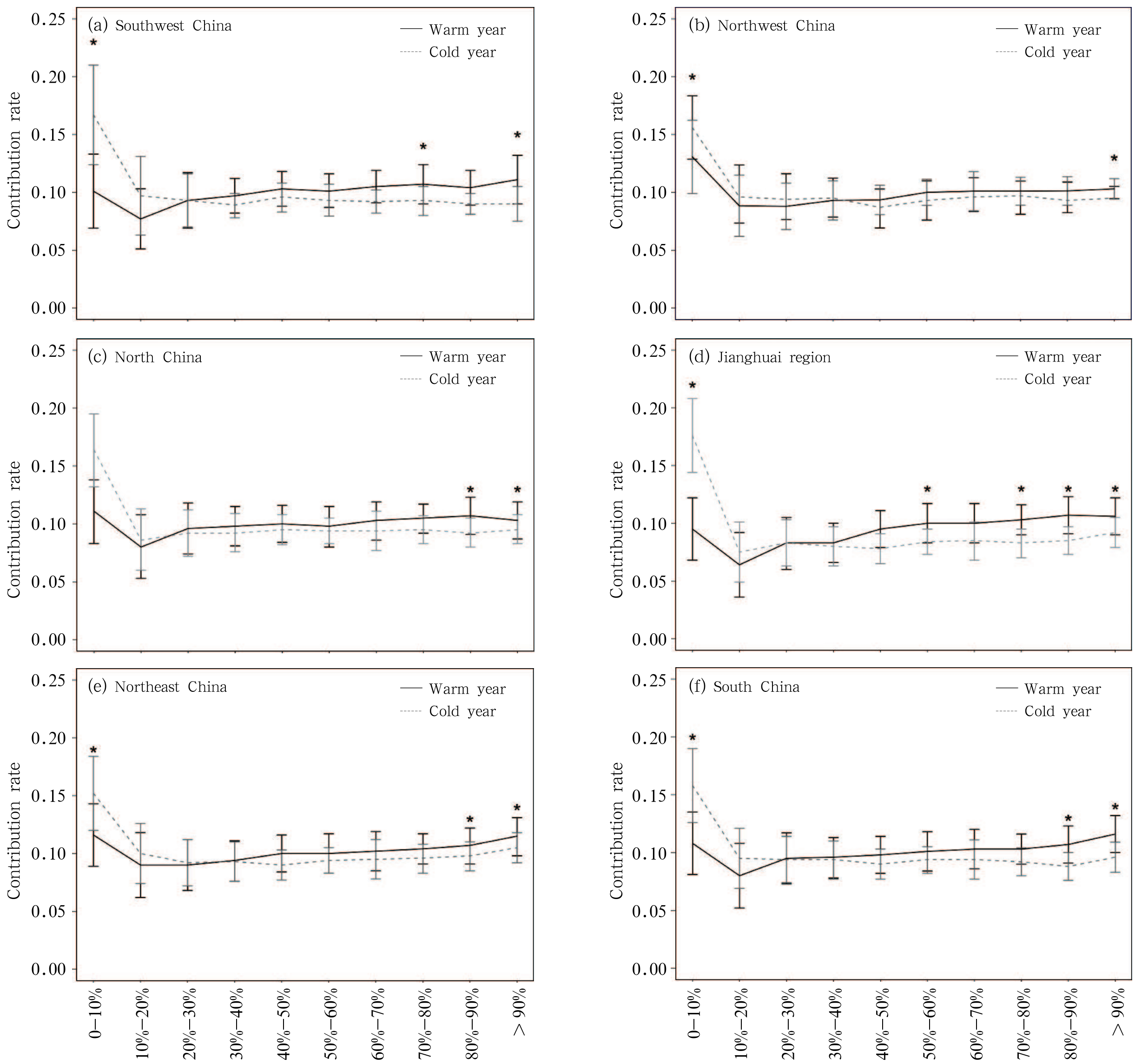

Fig. 3. Comparison of the contribution rates of precipitation days at different precipitation intensity levels between five typical warm years (black solid line) and five typical cold years (gray dashed line) for the six regions during 1961–2006. The x-axis represents the percentiles of the precipitation levels, and the y-axis represents the contribution rates of precipitation days. The * symbol indicates the value at the 95% confidence level. The dots represent the average contribution rates of various stations in the region at this level, and the vertical line represents the inter-station at twice the standard deviation.

and warm years are greatest when the precipitation intensity levels are greater than 80% (the corresponding daily precipitation is listed in Table 1). These data indicate that with the increasing temperature, the frequency distribution of daily precipitation shifts toward heavy precipitation in various regions of China.

Regardless of the precipitation intensity (both light and heavy), the differences in contribution rate for precipitation days between the cold and warm years are greater in the Jianghuai region, Southwest China, and South China than in other regions. In addition, the difference between the number of precipitation days of precipitation intensity less than 10% and greater than 80% between cold and warm years has a confidence level that is greater than 95% in the Jianghuai region, Southwest China, and South China. This phenomenon is especially obvious in the Jianghuai region (which has the greatest difference). In the Jianghuai region, the number of extremely light precipitation days decreases by 62% during warm years (Fig. 4a), while the number of extremely heavy precipitation days (with intensity greater than 95%) increases by 40% during warm years (Fig. 4a). These changes indicate that with increasing temperature, the reduced number of light precipitation days and increased number of heavy precipitation days are significant in the Jianghuai region, Southwest China, and South China. The vertical line in Fig. 3 represents twice the standard deviation of the contribution rates of precipitation at various stations in the region. A smaller standard deviation indicates a less dispersed contribution rate of precipitation among stations in the specific regions. Figure 3 indicates that the standard deviation of the contribution rates of extremely light precipitation days is greater than that of heavy precipitation days in all the six regions. These results indicate that the regional uncertainty of the contribution rates of extremely light precipitation days is greater than that of heavy precipitation days. In addition, the differences in the contribution rates of extremely light precipitation days between cold and warm years in the Jianghuai region and Southwest China are significantly greater than those in other regions. This finding indicates that the regional differences between warm and cold years are significant.

Figure 4 shows a comparison between the relative changes (in percentage) in the contribution rates of extremely light precipitation days and extremely heavy precipitation days between cold and warm years during summer and winter in the six regions. The relative changes between the cold and warm years in winter are significantly greater than that in summer in the Jianghuai region, South China, and Southwest China. In the Jianghuai region, the number of extremely light precipitation days in winter during cold years is less than in warm years by nearly 100% (the difference

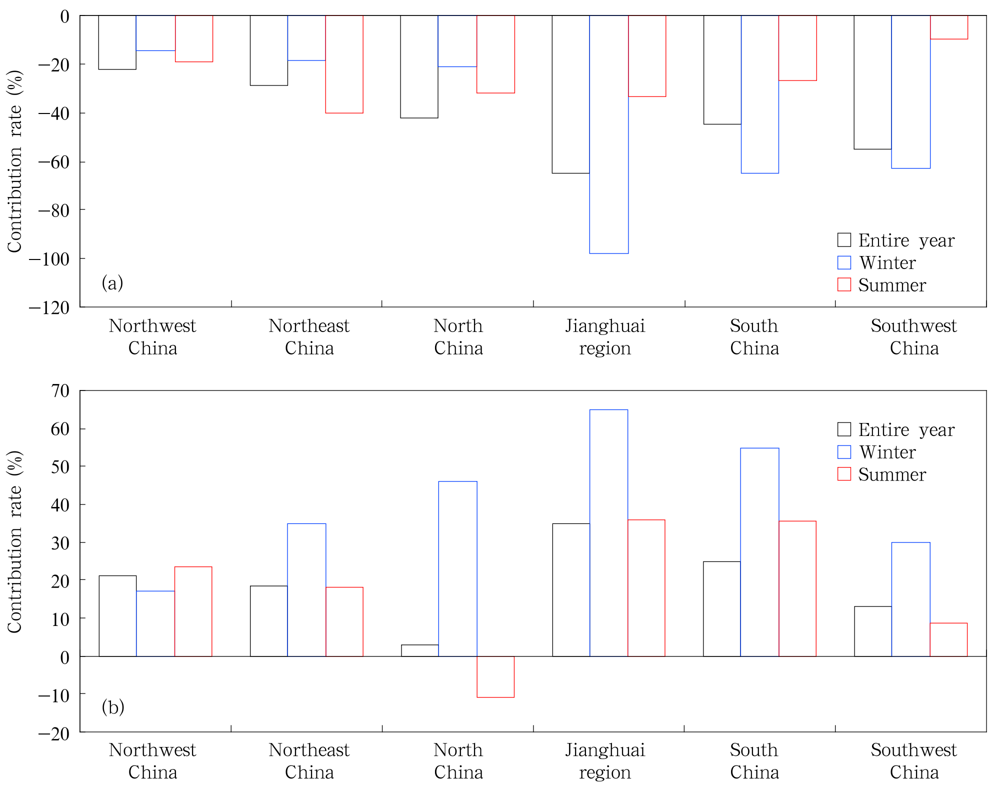

Fig. 4. Comparison of the contribution rate of (a) extreme light precipitation days to total precipitation days, and (b) heavy precipitation days to total precipitation days, during warm and cold years for the six regions of China.

is approximately thrice greater than the difference in summer). In Northeast China, Northwest China, and North China, these differences are slightly greater in summer than in winter (not significant). For extremely heavy precipitation, the differences between cold and warm years are greater in winter than in summer in Northeast China, the Jianghuai region, South China, and Southwest China. Especially, in the Jianghuai region and South China, the number of extremely heavy precipitation days in winter during warm years increases by 60% and 55%, respectively. In Northwest China, the difference is slightly greater in summer than in winter (not significant). In North China, extreme heavy precipitation days in winter increase by nearly 50% in warm years compared to cold years, but an opposite trend is observed in summer, with a decreased number of heavy precipitation days during warm years compared to cold years. The comparison between winter and summer indicates that the differences between cold and warm years for light and heavy precipitation are more significant in winter than summer for most regions, especially the Jianghuai region, South China, and Southwest China. These results suggest that the characteristics of decreased light precipitation days and increased heavy precipitation days are more significant in winter in China under a warming background (i.e., the changes in the spectral structure of precipitation in winter are primarily affected by the increasing global temperature whereas summer precipitation may be affected by additional factors) (Huang et al., 2008; Zhou et al., 2010).

In summary, in the context of global warming, the phenomena of decreasing light precipitation days and increasing heavy precipitation days occur in various regions of China. The threshold for these changes is generally observed when the precipitation intensity is in the 20th–30th percentile. The magnitude of the daily precipitation frequency distribution shift toward heavy precipitation varies from region to region. The characteristic of fewer light precipitation days and more heavy precipitation days is particularly significant in the Jianghuai region, Southwest China, and South China. In most regions, this response is significantly greater in winter than in summer, which indicates that changes in the spectral structure of winter precipitation are primarily affected by the increasing temperature.

3.2.2 Precipitation amount at different intensity levels

Figure 5 shows a comparison of the contribution rates of different precipitation intensities in various regions between typical cold and warm years. Here, the differences in the precipitation contribution rates between cold and warm years in various regions of China are obvious in the different contribution rates of heavy precipitation. Except in North China, the contribution rates of heavy precipitation with intensity above 90% (corresponding daily precipitation is listed in Table 1) are greater in warm years than cold years in Northwest China, Northeast China, the Jianghuai region, Southwest China, and South China. The contribution rates of precipitation from moderate intensity to the intensity that is less than 80%–90% level are slightly less during warm years than cold years (Table 1). In North China, the contribution rates of precipitation with an intensity of less than 60%–70% (see Table 1 for daily precipitation) or greater than 90% are less during warm years than cold years. However, the contribution rates of precipitation at other intensities are slightly greater in warm years than cold years. The differences in the precipitation contribution rates between cold and warm years are small for light precipitation; however, the differences gradually increase with increasing precipitation intensity. The regions with large differences between cold and warm years include the Jianghuai region, South China, and Southwest China, indicating that there is an increased contribution of heavy precipitation to the total precipitation with the increasing temperature in these regions. In addition, the comparisons in Fig. 3 also show that the difference in the contribution rates for precipitation days between cold and warm years is greater than the contribution rate of the precipitation amount.

In summary, except in North China, the precipitation characteristics in the Jianghuai region, Northwest China, Northeast China, Southwest China, and South China show an increasing number of heavy precipitation days (with increasing heavy precipitation)

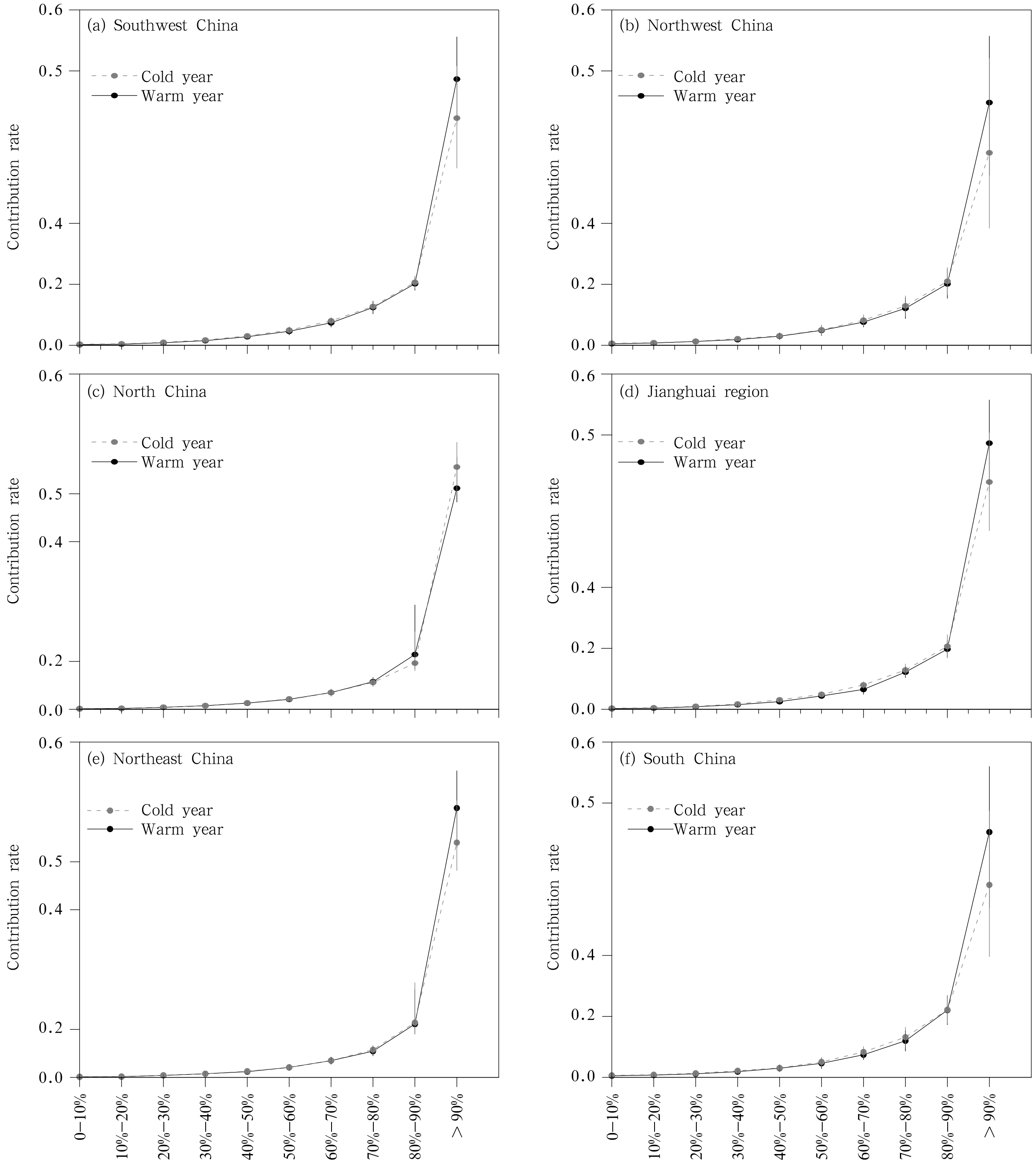

Fig. 5. Comparison of the contribution rates of various precipitation levels in different regions from 1961 to 2006. The black solid line represents warm years, and the gray dotted line represents cold years. The x-axis represents the percentile of precipitation levels, and the y-axis represents the contribution rate of the precipitation amount. The dots represent the average contribution rates of various stations in the region at this level, and the vertical line represents the inter-station at twice the standard deviation. In order to clearly illustrate the turning point of different precipitation intensities between cold and warm years and heavy precipitation contribution, the non-equidistant coordinate axis is applied in Fig.5.

and a decreasing number of light precipitation days (with decreasing light precipitation). The increasing amplitude of heavy precipitation days and heavy precipitation is positively correlated with the precipitation intensity (i.e., greater increase amplitude with greater intensity). However, the turning thresholds between cold and warm years for the number of precipitation days and the amount of precipitation are slightly different in different regions. The turning threshold for the difference of precipitation days between cold and warm years generally occurs at the precipitation intensity of 20%–30%, whereas it is 80%–90% for precipitation amounts. The difference is significantly greater for precipitation days than for the precipitation amount. In North China, the precipitation characteristics are similar to the other regions regarding precipitation days. However, when the precipitation intensity is less than 60%–70% or greater than 90%, the differences between cold and warm years are smaller during warm years than cold years, while at other precipitation intensities, these differences are greater in warm years than cold years. These results indicate that the responses of precipitation distribution spectra to global warming are different in different regions. With increasing temperature, the characteristics of a decreasing number of light precipitation days, an increasing number of heavy precipitation days, and increasing heavy precipitation are all more significant in the warm and humid regions (the Jianghuai region, South China, and Southwest China) than in the cold and arid (semi-arid) regions (North China, Northwest China, and Northeast China). In addition, the changes in light precipitation and extreme precipitation are both more significant in winter than summer, indicating that global warming has an increasing effect on changes in the spectral structure of precipitation in winter than in summer. With the increasing temperature, the distribution of the number of precipitation days and precipitation amount display characteristics of shifting to heavy precipitation, which results in an "increasing number of heavy precipitation days and heavy precipitation amount, and decreasing number of light precipitation days and light precipitation amount."

According to the Clausius-Clapeyron equation, the saturated vapor pressure increases at a rate of 7% K^{-1} with increasing air temperature. Temperature rising directly increases the vapor content in the atmosphere, which increases the precipitation intensity (Trenberth, 1998). Therefore, it is reasonable that with the increasing temperature, both the number of heavy precipitation days and heavy precipitation amount increase in most regions, which is also consistent with previous research (Zhai et al., 2007; Zhu et al., 2009). A recent publication by Yu and Jian (2012) demonstrates that the relationship between extreme precipitation and temperature exhibits significant regional differences. With an increasing temperature in North China, the changes of extreme precipitation do not show a significant trend, which is related to the decreasing water vapor transport. In the south regions, however, the ample water vapor limits the changes in relative humidity, which increases the extreme precipitation. In addition to being affected by air temperature, the decrease in light precipitation is also related to human activities, such as the aerosol emissions and the underlying surface changes. Recent studies (Rosenfeld et al., 2008; Qian et al., 2009; Wu and Fu, 2013) indicate that an increased amount of atmospheric aerosols significantly increases the cloud droplet concentration in the atmosphere and decreases the radius of the cloud droplets. These changes inhibit precipitation, which might reduce the light precipitation and eventually convert light precipitation to heavy precipitation.

4. Comparison of the daily precipitation Γ distribution in different regions between cold and warm years

From a statistical perspective, the changes in the contribution rates of precipitation at different intensity levels reflect the changes in the probability density distribution function of precipitation. Therefore, we use the Γ distribution function to fit the distribution of daily precipitation and analyze the parameters of the distribution function to determine the statistical significance of changes in the contribution rates of different precipitation intensity levels.

The Γ distribution fitting is performed on the daily precipitation data from 404 representative observation stations in China, and the goodness of fit is verified by using the K-S method. The daily precipitation distribution of all the stations fits the two-parameter Γ distribution. According to the definition of the Γ distribution, changes in the shape parameter α and scale parameter β influence the shape of the probability distribution function. When β is a constant and α increases, the skewness of the Γ distribution curve decreases, indicating increasing daily precipitation. When α is a constant and β increases, the dispersion of the Γ distribution curve increases, indicating that extreme precipitation events tend to increase. Therefore, changes in the Γ distribution parameters in different climatic contexts can reflect changes in the spectral structure of the precipitation intensity.

The daily precipitation data are fitted with the Γ distribution function in the six regions of China for the five warm and five cold years, respectively. The fit Γ distribution parameter of daily precipitation is set as $f_{\rm w}(\alpha, \beta)$ in the warm years, and $f_{\rm c}(\alpha, \beta)$ in the cold years. In addition, the fit Γ distribution parameter of daily precipitation in the past 46 years is set as $f_{\rm s}(\alpha, \beta)$.

The change rate of the Γ distribution parameters is defined as $\dfrac{f_{\rm w}(\alpha,\beta)-f_{\rm c}(\alpha,\beta)}{f_{\rm s}(\alpha,\beta)}$.

4.1 Changes in the shape parameter

Figure 6 shows the distribution of the change rates for the shape parameter α of the daily precipitation Γ distribution in the six regions of China in the cold and warm years. Other than a few stations in Northeast China, Northwest China, and Southwest China, the value of α is greater in the warm years than cold years for most of the stations. Among these regions, the Jianghuai region shows the greatest change in α with an average regional change of more than 20%. In the northeast and northwest regions, the changes in α are relatively small and generally less than 10%. In North China, South China, and Southwest China, the value of α increases by approximately 15%. These results indicate that with the increasing temperature, the skewness of the daily precipitation Γ distribution decreases for most of the stations in the six regions of China. In addition, the daily precipitation Γ distribution in various regions of China shifts towards heavy precipitation and average daily precipitation intensity trends to increase. In the Jianghuai region and South China, the value of α significantly increases, meaning that the shift of daily precipitation towards heavy precipitation is more significant, and the increases in the average daily precipitation intensity is greater. These results are consistent with the analyses in previous sections.

4.2 Changes in the scale parameter

The change rates of the scale parameter β for the cold and warm years in relation to the daily precipitation Γ distribution of various stations in the six regions of China are shown in Fig. 7. For most stations, β is greater in warm years than cold years. However, relatively concentrated areas with decreasing β values occur in central North China, eastern Jianghuai region, eastern Northwest China, and northern Southwest China. In terms of regional averages, the value of β increases in all regions except for North China. The value of β increases the most in Northwest China by up to approximately 15%. In Northeast China, the Jianghuai region, South China, and Southwest China, the amplitude of β changes by approximately 5%. In North China, the change rate of β decreases by approximately –4.3%, which may be related to decadal decreased changes in regional precipitation.

Compared with changes in α, changes in β are smaller in all of the regions except Northwest China, which suggests that the increase of α for the daily precipitation Γ distribution plays an important role and dispersion increases slightly with global warming. In addition, these results indicate that the daily precipitation in various regions of China shifts towards heavy precipitation and the number of extreme precipitation events increases slightly with increasing temperature. These results are consistent with the above analyses. In Northwest China, changes in β are greater than changes in α, suggesting that the occurrence of extreme precipitation events increases in this region with

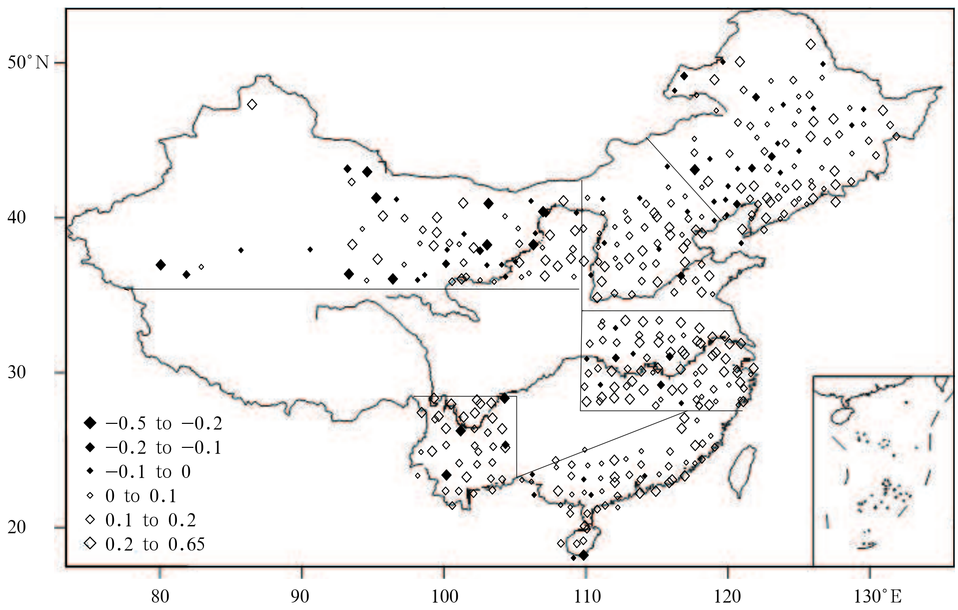

Fig. 6. Spatial distribution of the change rates of the shape parameter α in the typical warm and cold years.

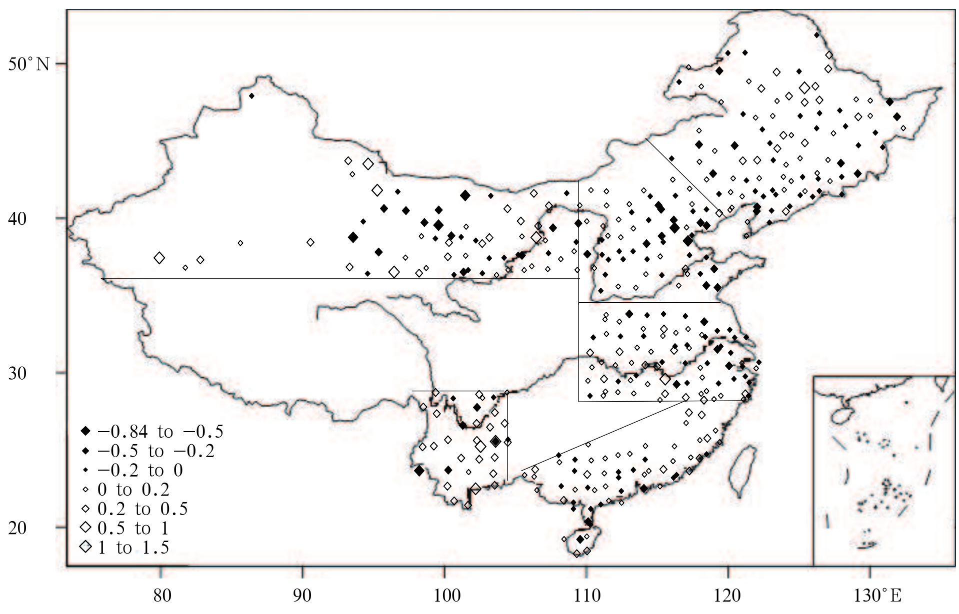

Fig. 7. As in Fig. 6, but for the scale parameter β.

global warming. In North China, the β value decreases slightly and dispersion decreases. In contrast, the value of α increases significantly, suggesting that under the warming, this region has an increasing precipitation intensity and decreasing number of extreme precipitation events.

5. Conclusions and discussion

The characteristics of the precipitation intensity spectrum in six regions of China (Northwest China, Northeast China, North China, the Jianghuai region, Southwest China, and South China) are analyzed based on the daily precipitation data from 404 meteorological stations in China from 1961 to 2006. Responses of the spectral structure of precipitation to global warming are investigated for different regions in China. By fitting the daily precipitation distribution with the Γ function, changes in the shape (α) and scale (β) parameters of the Γ distribution functions of different regions during the cold and warm years are discussed, and the following results are obtained.

(1) Under a warming background, the characteristics of precipitation in five regions (Northwest China, Northeast China, the Jianghuai region, Southwest China, and South China) show an increasing number of heavy precipitation days as well as heavy precipitation amount, and decreasing number of light precipitation days as well as light precipitation amount. However, the turning threshold is slightly different for the changes in the number of precipitation days and precipitation amount. The turning threshold for the difference of precipitation days between the cold and warm years generally occurs at precipitation intensities of 20%–30%, whereas for the total amount of precipitation, it occurs at precipitation intensities of 80%–90%. These results suggest that with the increasing temperature, the precipitation distribution shifts towards heavy precipitation for the number of precipitation days and precipitation amount. The characteristics of the difference of heavy precipitation days in North China are similar to that in the other five regions; however, the contribution rate of heavy precipitation with intensities of more than 90% is smaller in warm years than cold years.

(2) The responses of precipitation intensity spectrum to global warming differ from place to place. The characteristics of fewer light precipitation days, more heavy precipitation days, and more heavy precipitation are much more significant in the warm and humid areas (the Jianghuai region, South China, and Southwest China) than cold and arid (semi-arid) regions (North China, Northwest China, and Northeast China). In addition, changes in light precipitation and extreme precipitation are significantly greater in winter than summer.

(3) The results of the statistical analysis suggest that the daily precipitation of various stations fit the two-parameter Γ distribution in Northwest China, Northeast China, the Jianghuai region, Southwest China, and South China. Under global warming, there are differences in the change rates of α and β in the Γ distribution for different regions. However, the shape parameter α shows a significant increase, and scale parameter β shows a slight increase. These results indicate that with the increasing temperature, in the Γ distribution, there is a shift of daily precipitation toward heavy precipitation and increased dispersion in various regions of China.

In the present study, changes in the distribution structure of the precipitation frequency in various regions of China are analyzed by using observational data and statistical modelling. Because there are differences in the factors (moreover, the factors also differ from region to region) that affect changes in the precipitation spectrum, additional model validation and theoretical explanations are required.

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