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ORIGINAL PAPER

Latest update of the climatology and changes in the seasonal distribution of precipitation over China

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Abstract Based on daily precipitation data from 524 meteorological stations in China during the period 1960–2009, the climatology and the temporal changes (trends, interannual, and decadal variations) in the proportion of seasonal precipitation to the total annual precipitation were analyzed on both national and regional scales. Results indicated that (1) for the whole country, the climatology in the seasonal distribution of precipitation showed that the proportion accounted for 55 % in summer (June–August), for around 20 % in both spring (March–May) and autumn (September–November), and around 5 % in winter (December–February). But the spatial features were region-dependent. The primary precipitation regime, "summer–autumn–spring–winter", was located in central and eastern regions which were north of the Huaihe River, in eastern Tibet, and in western Southwest China. The secondary regime, "summer–spring–autumn–winter", appeared in the regions south of the Huaihe River, except Jiangnan where spring precipitation dominated, and the southeastern Hainan Island where autumn precipitation prevailed. (2) For the temporal changes on the national scale, first, where the trends were concerned, the proportion of winter precipitation showed a significantly increasing trend, while that of the other three seasons did not show any significant trends. Second, for the interannual variation, the variability in summer was the largest among the four seasons and that in winter was the smallest. Then, on the decadal scale, China experienced a sharp decrease only in the proportion of summer precipitation in 2000. (3) For the temporal changes on the regional scale, all the concerned 11 geographic regions of China underwent increasing trends in the proportion of winter precipitation. For spring, it decreased over the regions south of the Yellow River but increased elsewhere. The trend in the proportion of summer precipitation was generally opposite to that of spring. For autumn, it decreased over the other ten regions except Inner Mongolia with no trend. It is noted that the interannual variability of precipitation seasonality is large over North China, Huanghuai, and Jianghuai; its decadal variability is large over the other regions, especially over those regions south of the Yangtze River.

1 Introduction

Detection, causes, and projection of climate change over the globe have been widely discussed recently (IPCC 2007), and precipitation is one of the most important indicators in the study of climate change. The trend in global annual land precipitation is statistically insignificant over the last 100 years (IPCC 2007), but the pattern of precipitation change is spatially and seasonally variable. On the spatial scale, it has become significantly wetter in eastern parts of North and South America, northern Europe, and northern and central Asia, but drier in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia (Dai et al. 2004). On the

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temporal scale, global annual land precipitation increased overall before the 1950s, declined until the early 1990s, and has since then recovered (Peterson and Vose 1997; Mitchell and Jones 2005). As to the attribution of precipitation change, anthropogenic factors appear to have influenced the latitudinal pattern of land precipitation and heavy precipitation over the twentieth century, and volcanic forcing is also detectable as having a role in global mean land precipitation (Zhang et al. 2007). In the future, warming would generally increase the spatial variability of global precipitation, in which wet regions become wetter and dry regions become drier on the global scale (Russo and Sterl 2012).

Precipitation change has also been studied intensively in China. There is a statistically insignificant trend in total precipitation for China as a whole over the past 50 years, but evidence for regional and seasonal trend patterns is detectable (Zhai et al. 2005; Ding et al. 2007). Total precipitation has significantly increased in northwestern China and in the mid-lower reaches of the Yangtze River valley, but decreased in North China. Precipitation in all seasons has increased in western China. Winter precipitation has increased in the southern parts of eastern China but decreased in the northern parts. The trend in spring precipitation over eastern China has generally been the opposite to that of total precipitation, but the trend in summer precipitation has been the same with that of the annual precipitation. Autumn precipitation has decreased over most parts of China. In the future, total precipitation is projected to increase in most parts of China, but large uncertainty exists in the projection of precipitation (Jiang et al. 2004; Zhou et al. 2008).

The seasonality of precipitation is one of the most important aspects in the study of precipitation. The seasonal distribution of precipitation is of great importance for many (e.g., agricultural and hydrological) processes (Mo et al. 2005; Jia et al. 2009). Indeed, this issue has been widely addressed in many areas of the world (e.g., Kincer 1919; López-Moreno et al. 2009; de Luis et al. 2010; Arias et al. 2012; Liebmann et al. 2012). To our knowledge, however, the previous researches about seasonal distribution of precipitation over China are mainly about the total seasonal precipitation amount. Another important aspect of seasonal precipitation, namely the contribution of seasonal precipitation, has been given very little attention in China. The only example is the work by Ren et al. (2000), which involved a preliminary analysis of the trend in the proportion of seasonal precipitation during the period 1960–1996. Since the climatology of precipitation seasonality over China and its interannual and decadal changes over time have not been specifically investigated in the scientific literature, the motivations behind the present study were (1) to investigate the climatology in the proportion of seasonal precipitation to the total annual precipitation throughout China during the period 1960–2009, (2) to assess whether the proportion of seasonal precipitation has changed since 1960, and (3) to explore the climatology and temporal variation in the proportion of seasonal precipitation in each geographic region of China.

2 Data and methods

2.1 Data

Daily precipitation data from the China Meteorological Administration were obtained from 756 meteorological stations located throughout mainland China during the period 1960–2009. The data have been subject to quality-control procedures of the National Meteorological Information Center of China Meteorological Administration. Generally, a year was considered missing in a station record if it contained >10 % missing daily values. Each station record used also needed to have at least 10 years worth of data between 1960 and 2009, and a total of 737 stations were retained. Then, the further quality control of data has been done. According to Feng et al. (2004), the spatial outliers were checked and filled based on the 737 stations, and the missing values also were filled if there were less than six missing days for 1 month in this step. Thus, any given station was retained on the condition that it had no daily missing values between 1960 and 2009. In this manner, a total of 524 stations passed this procedure.

After checking the availability of data, we examined the possible inhomogeneity problem using standard normalized homogeneity test (SNHT) method and principal component analysis (PCA). First, the annual precipitation series of 524 stations were tested with the SNHT method as described in Jiang et al. (2008). Annual data were derived from monthly data, and monthly data were derived from daily data. In this procedure, 669 stations which had more than 25 non-missing years of data were used to create the reference series. After this procedure, 25 stations' series out of the 524 have been confirmed having singular values with a significance level of 0.05. Inhomogeneity of these 25 stations' series has been further assessed by PCA. According to Dai et al. (1997), monthly precipitation anomalies at each station were treated as 12 different time series and were checked whether any major common components exist in the 12 monthly time series of a station by employing PCA. A 7-year low-frequency filter was used to remove multiyear variations in station time series prior to the PCA, because the instrumental discontinuities generally occurred on the decadal scale. Based on the above two steps, 14 stations' series out of the 524 have been confirmed inhomogeneous. Then, we corrected the inhomogeneity in annual and monthly precipitation time series of the 14 stations based on the SNHT method. The results of homogeneity test of annual precipitation were shown in Table 1.

Table 1 Results of homogeneity test of annual precipitation

Correlation coefficient	Station number	Year at the breakpoint	$T_{s,\ \max}$	Correction factor
0.80	57776	1964	9.135	0.8977
0.75	50873	1966	9.390	0.8929
0.75	57996	1988	8.948	0.9437
0.75	58531	1963	11.503	1.1500
0.75	59096	1963	8.875	1.1607
0.70	53863	1970	9.183	1.1575
0.70	54363	1988	8.910	1.0864
0.70	54836	1992	8.564	1.1245
0.70	57046	1987	8.103	0.8876
0.70	57494	1979	10.108	1.1153
0.70	58477	1974	8.835	1.1293
0.70	58608	1993	9.990	1.0834
0.65	58345	1996	10.550	0.8994
0.65	58569	1965	11.210	0.8764

Correlation coefficient was calculated by the tested series and the reference series. In this study, if Ts, max SNHT statistic at some year exceeded the critical values at the 0.05 significance levels (Jiang et al. 2008), this time series was regarded as inhomogenous series before and after this year, and this year was regarded as the breakpoint. The inhomogenous time series were corrected through ratio correction, in other words, the homogenous time series were obtained by the correction factors multiplied by the tested series

The numbers of stations which were mentioned at above several steps, such as 737, 669, and 524, were marked in Fig. 1. Monthly precipitation data of the corrected 524 stations were applied to the subsequent analysis. Both annual and seasonal data were derived from the monthly data. Seasonal analyses were performed as the common procedure for winter (December–January–February), spring (March–April–May), summer (June–July–August), and autumn (September–October–November). The proportion of seasonal or monthly precipitation was the ratio of seasonal or monthly precipitation to the total annual precipitation.

2.2 Analysis techniques

To provide a single value for the entire country and subregions for a particular quantity, we computed an area-weighted average for the variable. Referring to Zhai et al. (2005), we first divided the country into 2° latitude by 2° longitude boxes and then calculated the box values as the arithmetic mean of all available station data in the box. Afterward, we used box values to compute the national and regional averages by taking the areas of the boxes as weights.

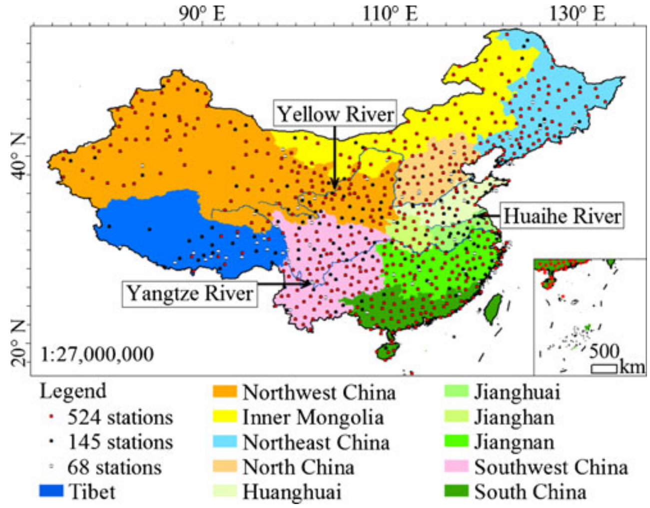

Fig. 1 Spatial distribution of meteorological stations for the period 1960–2009. In the text, 669 stations were 524 *red* stations plus 145 *black* stations, and 737 stations were 669 stations plus 68 *white* stations. The Yangtze River, Huaihe River, and Yellow River are indicated in *blue curves*. *Colored polygons* correspond to 11 geographic regions of China, defined by China Meteorological Administration: Northwest China, Inner Mongolia, Northeast China, North China, Huanghuai, Jianghuai, Tibet, Jianghan, Jiangnan, Southwest China, and South China

In order to examine the temporal variation of the proportion of seasonal precipitation, linear trends and climatic jumps were analyzed by linear regression and the moving t test (MTT), respectively. Using linear regression, we obtained the slope of the line of best fit for variable as a function of time to measure the magnitude of change that took place between 1960 and 2009. By means of a two-tailed t test with a confidence level of 95 %, the significance of the linear trend variation was examined. The MTT is a common method to detect climatic jumps (e.g., Afifi and Azen 1972; Fu and Wang 1992; Yan et al. 1992). It does this in a series by assessing the difference between two subsequence means. Under the null hypothesis that the difference of the two subsequence means is zero, the t statistic is given as:

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{n_1 s_1^2 + n_2 s_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where n_1, $\overline{x_1}$, and s_1^2 indicate the size, mean, and variance of the x_1 subsequence, respectively; and, correspondingly, n_2, $\overline{x_2}$, and s_2^2 indicate those of the x_2 subsequence.

The t statistic series is then obtained by the two subsequences being moved forward year by year. If the t statistic variable reaches a maximum value around a year that exceeds the threshold at a given significance level, a jump occurs. In the process of MTT, a significance level of 0.01 was applied; both n_1 and n_2 were set to 10, which corresponded to decadal changes. In addition, based on the spatial analysis tool of a geographic information system, the inverse distance weighted method was applied to display spatial distribution of variable by setting the power value and the number of neighbor sites as 2 and 15, respectively.

3 Seasonal distribution of precipitation over China

3.1 Climatology in the proportion of seasonal precipitation

According to the area-averaged climatology in the proportion of seasonal precipitation to the total annual precipitation over China during the period 1960–2009, summer precipitation was the highest, reaching 55.4 %, more than half of the total annual precipitation, whereas winter precipitation was the lowest, at only 5.6 %. The proportions for spring and autumn were 19.8 and 19.2 %, respectively. To better understand the seasonality of precipitation in China, the spatial pattern of the climatology in the proportion of seasonal precipitation to total annual precipitation is shown in Fig. 2. In winter, the highest proportion of precipitation appeared in southeastern and northwestern China, while the lowest proportion extended from northeastern to southwestern China, with this proportion being less than 15 % in most parts of China. The spatial feature of the proportion of spring precipitation was similar to winter: the highest values appeared in southeastern China, while the lowest values occurred in northeastern China and Tibet. The distribution of the proportion of summer precipitation was opposite to spring, with the largest values located in the north of the Yellow River and Tibet, while the smallest values were in southeastern China. In addition, the spatial distribution of the proportion of summer precipitation in Northeast China was similar to that found by Liang et al. (2011). The highest proportion of autumn precipitation was seen in southern South China, and the lowest proportion occurred in southwestern Northwest China and parts of southeastern China. The spatial distributions of the climatology in the proportion of monthly precipitation were almost consistent with the spatial distribution of the climatology in the proportion of corresponding seasonal precipitation (Fig. 3).

Based on the above analysis, we obtained seven permutations about precipitation regimes in spring, summer, autumn, and winter for China during the period 1960–2009 (Fig. 4). The spatial distribution of seasonal precipitation regimes showed that summer precipitation dominated most parts of China. The primary precipitation regime, “summer–autumn–spring–winter”, extended from Northeast China into southwestern China, and it also displayed in northern Xinjiang province and in the eastern Hainan Island. The second most dominant regime, “summer–spring–autumn–winter”, occurred across almost the rest of the country, except the majority of Jiangnan where spring precipitation dominated, the southeastern Hainan Island where autumn precipitation prevailed, and small parts of southern Xinjiang province where “summer–spring–winter–autumn” was the controlling regime. The other permutations were not common precipitation regimes for China.

3.2 Temporal variations in the proportion of seasonal precipitation

As mentioned in the introduction, some studies have found evidence for regional and seasonal trend patterns

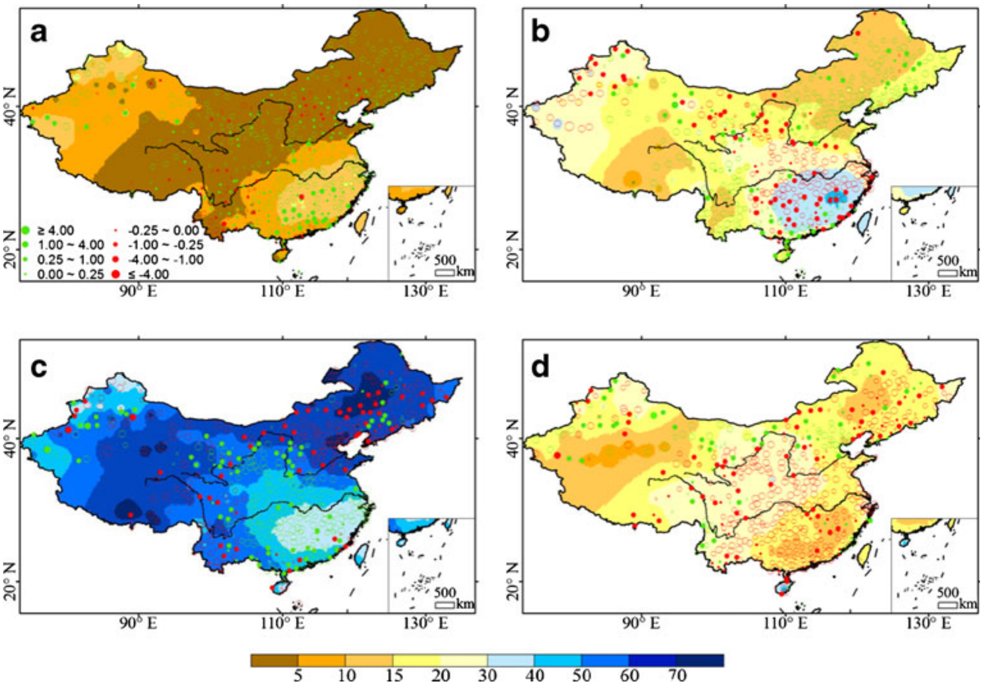

Fig. 2 Spatial distribution of the climatology (%) in the proportion of (**a**) winter, (**b**) spring, (**c**) summer, and (**d**) autumn precipitation throughout China during the period 1960–2009. The *green* (*red*) *circle* indicates an (a) increasing (decreasing) trend, and *solid circle* signifies the significant trend at the 0.05 level

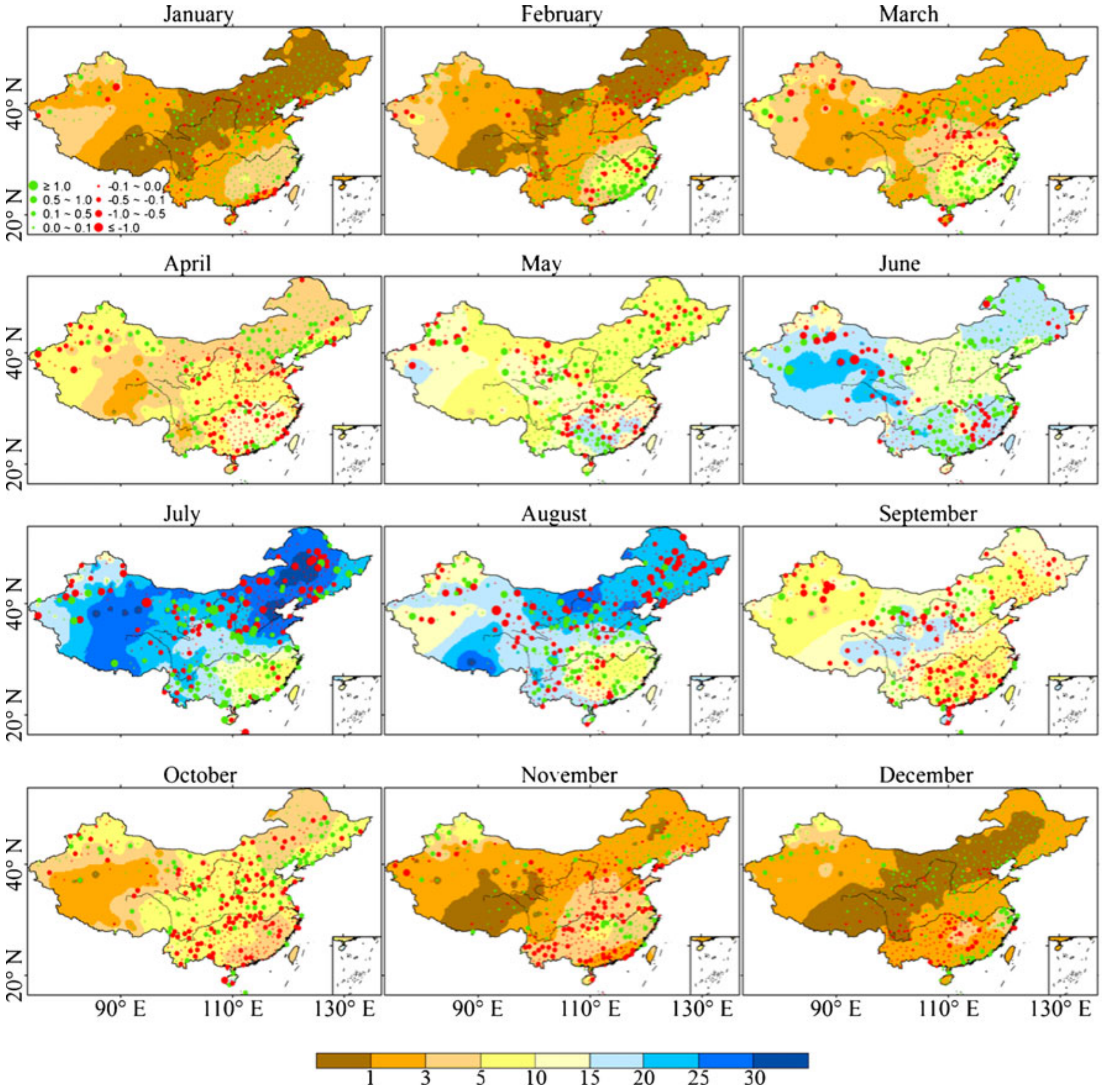

Fig. 3 Spatial distribution of climatology (*shading*, in %) and trends (*solid circle* and *plus sign*, in % per decade) in the proportion of monthly precipitation during the period 1960–2009. The *green* (*red*) *solid circle* indicates significantly increasing (decreasing) trend at the 0.05 level. The *plus sign* indicates a station without a significant trend at the 0.05 level

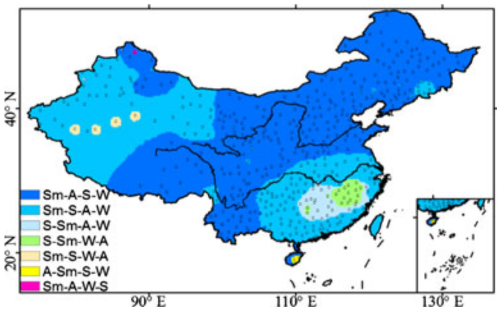

Fig. 4 Seasonal precipitation regimes in China during the period 1960–2009. *Sm–A–S–W* refers to "summer–autumn–spring–winter", meaning that the proportion of precipitation was the largest in summer, second-largest in autumn, third-largest in spring, and the lowest in winter. *Other colors* can be deduced in the same way

in precipitation over China over the past 50 years. Accordingly, an important question is whether the seasonality of precipitation has changed during this period, and if so, how did it change?

Area-averaged time series of the proportion of seasonal precipitation to total annual precipitation for China between 1960 and 2009 and the corresponding moving t test statistics were presented in Fig. 5. The results shown in this figure demonstrated a statistically significant increasing trend for the proportion of winter precipitation at a rate of 0.35 % per decade. A statistically insignificant upward trend of 0.16 % per decade for the proportion of spring precipitation and a statistically insignificant downward trend of −0.35 % per decade for the proportion of autumn precipitation were seen, and no climatic jump occurred on the decadal scale during

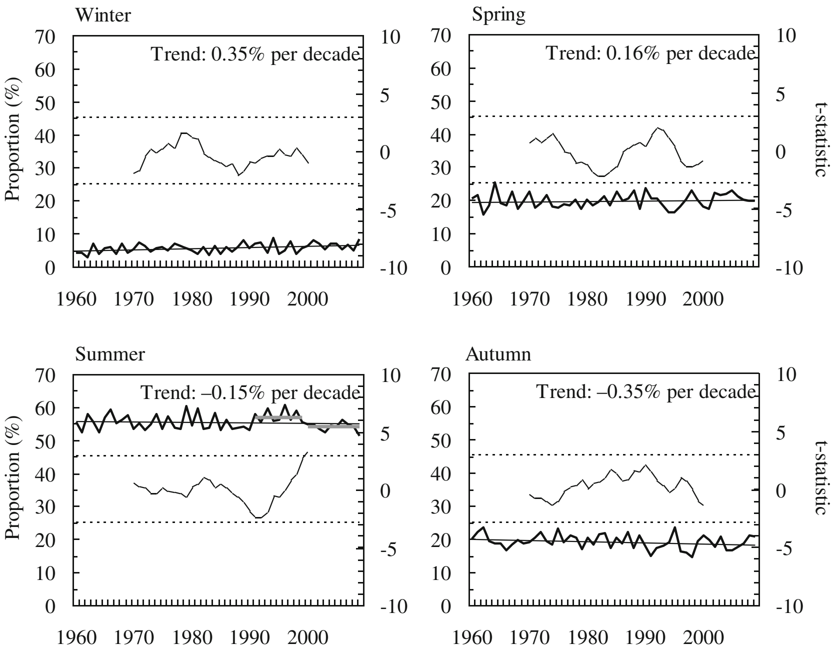

Fig. 5 Area-averaged time series (*thick curves*) of the proportion of seasonal precipitation to total annual precipitation for China during the period 1960–2009 with the linear trends (*black straight solid lines*), and the corresponding moving *t* test statistics series (*thin curves*), in which a maximum exceeding the 0.01 significance level (*dashed lines*) indicates a significant climatic jump. The *horizontal gray solid lines* in the series highlight the two periods before and after the climatic jump

the study period for both spring and autumn. The proportion of summer precipitation showed a statistically insignificant downward trend of 0.15 % per decade, whereas it experienced a sharp increase in 2000.

Since the spatial distribution of the climatology in the proportion of seasonal precipitation over the country is irregular, the geographical distribution of trends in the proportion of precipitation for each season (Fig. 2) and each month (Fig. 3) during the period 1960–2009 was further analyzed. For winter, the precipitation proportion increased by less than 2.16 % per decade in most parts of China and decreased by less than 0.44 % per decade in western Southwest China, some parts of North China, parts of the southeast coast, and some other small regions. In general, the distribution of trends in the proportion of winter precipitation was similar to that reported by Ren et al. (2000), but opposite to their result in Northeast China. The trends over southern Northeast China and parts of the lower reaches of the Yellow River increased significantly by 0.25–1.00 % per decade, mainly caused by the rise in December and January. The trends over southeastern South China increased significantly by more than 1.00 % per decade, primarily due to the rise in February and December, while the significantly increasing trends over northern South China were mainly due to January and February.

For spring, the trend in the proportion of precipitation varied between −4.22 and 2.83 % per decade. Increasing trends were found in Northeast China, North China, northeastern Huanghuai, central Northwest China, Tibet, western Southwest China, and southern South China; decreasing trends were found in western and eastern Northwest China, western Huanghuai, Jianghuai, Jianghan, Jiangnan, and northern South China. Note that the contributions of each month in spring were different. Significant positive trends over parts of Northeast China and central Northwest China were mainly due to the increase in March and April, while other significant positive trends over southern South China were due to the decreases in March or May. As to the significant negative trends over Jiangnan, May and April played an important role. All the spring months made contribution to the significantly decreasing trends over western and eastern Northwest China. There was no significant decreasing trend in the proportion of spring precipitation over Jiangnan, because significant negative trends in April and May were counteracted by the significant positive trend in March.

For summer, the trend ranged from −6.16 to 3.66 % per decade, and it generally showed the opposite sign to that of spring in China, except over western Inner Mongolia, western South China, and northwestern and southeastern Northwest China. In parts of Inner Mongolia, significant negative trends were mainly due to the decreases in July and August in spite of the increasing trend in June. Significant positive trends over parts of Southeast China were derived from the combined decreases in June and July. Significant positive trends over western North China were due to the combined increases in June and August. On the other hand, the trends north of 35° N in June showed the opposite sign to that in summer.

For autumn, the trend varied from −2.82 to 4.33 % per decade. Downward trends dominated over most parts of China, except western Inner Mongolia, the middle of Northwest China, eastern North China, and some other small regions. Significant downward trends over most eastern regions south of the Yellow River were derived from the combined decreases in September, October, and November, especially for September. On the contrary, upward trends over North China, Inner Mongolia, and parts of Northwest China were observed for September.

4 Seasonality of precipitation in eleven regions of China

4.1 Climatology in the proportion of seasonal precipitation

According to the above analysis, it was necessary to explore the regional feature of the seasonal distribution of precipitation. The climatology in the proportion of seasonal and monthly precipitation to total annual precipitation in 11 geographic regions (marked in Fig. 1) of China during the period 1960–2009 was shown in Table 2 and Fig. 6, respectively. On one hand, there were three common characteristics for the six regions located in southwestern China and north of the Huaihe River, which were Inner Mongolia, Northeast China, North China, Huanghuai, Tibet, and Southwest China. First, the seasonal precipitation regime was summer–autumn–spring–winter. The summer proportion accounted for 50 % or more of the total annual precipitation, while the winter proportion was less than 7 %. Second, there was a single peak in the monthly precipitation distribution in July, which was stronger over eastern (northern) regions than over western (southern) regions. Lastly, the proportion in August was greater than in June. On the other hand, regarding the other four regions south of the Huaihe River (i.e., Jianghuai, Jianghan, Jiangnan, and South China), the common feature was that the seasonal precipitation regime was summer–spring–autumn–winter, with the summer proportions being around 40 % and the winter proportions greater than 7 %. However, the regional precipitation distributions were different from month to month. For Jianghan and Jianghuai, there was a weak single peak in July, and the proportion in August was less than that in June. For Jiangnan, the monthly precipitation distribution differed from the other regions, with the peak value taking place in June rather than in July. Interestingly, there were two peaks in the monthly distribution over South China, which appeared in June and August, respectively. In addition, for Northwest China, the seasonal precipitation regime was summer–spring–autumn–winter, with the summer proportions more than 50 % and the winter proportions less than 7 %. There was a single peak in the monthly precipitation distribution in July, and the proportion in August was similar in June. These regional precipitation characteristics in China were related to the advance and retreat of the East Asian summer monsoon precipitation (Tao and Chen 1987; Wang and Ding 2008).

4.2 Temporal variations in the proportion of seasonal precipitation

The trends in the proportion of seasonal precipitation to total annual precipitation for 11 geographic regions of China during the period 1960–2009 were also displayed in Table 2. The proportion of winter precipitation increased in all the 11 regions. It significantly increased by 0.80 % per decade in Jianghuai, by 0.53 % per decade in Northwest China, by 0.46 % per decade in Jianghan, by 0.30 % per decade in Northeast China, and by 0.22 % per decade in Inner Mongolia. The increasing trends in northern China were generally owing to the positive trends in all the winter months, and those in southern China were chiefly caused by the positive trend in January (Fig. 6). The proportion of spring precipitation showed a decreasing trend in Huanghuai, Jianghuai, Jianghan and Jiangnan, and it decreased significantly by 1.02 % per decade in Jianghuai and by 0.65 % per decade in Jianghan. By contrast, it showed an increasing trend in the other regions, especially in Tibet where it increased significantly by 0.77 % per decade, in Northeast China where it increased by 0.73 % per decade, and in Southwest China where the increase was 0.54 % per decade. The proportion of summer precipitation showed a non-significant decreasing trend in northern China, including Northeast China, Northwest China, North China, and Inner Mongolia, owing to the combination of an increasing trend in June and the decreasing trends in July and August on the monthly scale. It also displayed a non-significant decreasing trend in Tibet, but owing to the negative trend during June and August. Meanwhile, it increased significantly by 1.43 % per decade in Jianghan, by 1.37 % per decade in Jianghuai, and by 0.98 % per decade in Jiangnan because of the positive trend in June, July, and August, especially in July. The proportion of autumn precipitation decreased in most regions except Inner Mongolia, and it decreased significantly by 1.30 % per decade in Huanghuai, by 1.24 % per decade in Jianghan, by 1.15 % per decade in Jianghuai, by 0.72 % per decade in Jiangnan, and by 0.57 % per decade in Southwest China. For Huanghuai, Jianghan, and Jianghuai, these decreasing trends in autumn were mainly attributed to the decreasing trend in September, and for Jiangnan and Southwest China they were due to the combined decreases in all the three autumn months.

Apart from the above analysis about the trends in seasonality of precipitation in the 11 regions, another important temporal feature was the variability on both interannual and decadal scales. Figure 7 showed the interannual and decadal variations in the proportion of seasonal precipitation during the period 1960–2009. As a whole, the interannual variability in summer was the largest among the four seasons and that in winter was the smallest. In terms of geographic distribution, the interannual variability over eastern regions (e.g., North China, Jianghan, Huanghuai, and South China)

Table 2 Climatology (%) and trends (% per decade) in the proportion of seasonal precipitation for 11 geographic regions of China

		Northwest China	Inner Mongolia	Northeast China	North China	Huanghuai	Jianghuai	Tibet	Jianghan	Jiangnan	Southwest China	South China
Winter	Mean	5.8	2.6	3.0	3.3	6.4	11.0	2.2	8.2	11.7	4.5	7.3
	Trend	0.53[a]	0.22[a]	0.30[a]	0.17	0.49	0.80[a]	0.09	0.46[a]	0.38	0.02	0.16
Spring	Mean	19.7	14.6	14.7	15.9	20.1	27.9	13.0	29.1	34.5	20.1	25.6
	Trend	0.21	0.41	0.73[a]	0.54	−0.25	−1.02[a]	0.77[a]	−0.65[a]	−0.65	0.54[a]	0.21
Summer	Mean	56.3	65.1	65.3	60.3	52.6	43.1	66.4	41.7	37.6	52.6	46.4
	Trend	−0.22	−0.65	−0.67	−0.31	1.07	1.37[a]	−0.63	1.43[a]	0.98[a]	0.01	0.37
Autumn	Mean	18.2	17.7	17.0	20.5	20.9	18.0	18.5	21.0	16.2	22.8	20.8
	Trend	−0.10	−0.01	−0.35	−0.38	−1.30[a]	−1.15[a]	−0.22	−1.24[a]	−0.72[a]	−0.57[a]	−0.75

[a] Statistically significant change at the 0.05 level

was larger overall than that over western regions. On the decadal scale, we only checked the abrupt signals of the proportion of seasonal precipitation. In Fig. 5, China experienced a sharp decrease in the proportion of summer precipitation in the early 2000s. However, the regional decadal precipitation changes disagreed with those for the whole of China. In the early 1970s, Southwest China experienced an abrupt increase during spring. In the late 1970s, a sharp decrease occurred over Jianghan during spring, while a significant increase occurred over South China during spring. In the early 1980s, a sharp decrease took place over both South China during summer and over Northwest China during autumn and winter, while a rapid increase occurred over Northwest China during spring. In the early 1990s, a rapid increase emerged over South China and Jiangnan during summer, while a fast decrease came about over Jiangnan during spring and autumn. In the mid-1990s, a rapid decrease appeared over Southwest China during autumn. In the late 1990s, a sharp decrease showed over Inner Mongolia during summer, while a sharp increase showed over Tibet during spring.

5 Conclusions and discussion

Based on daily precipitation data during the period 1960–2009 from 524 meteorological stations in China, the climatology and the temporal change in the proportion of seasonal precipitation to total annual precipitation were analyzed on both the national and regional scales. In terms of the climatology in the proportion of seasonal precipitation for the whole country, the summer proportion accounted for more than 55 %, while both spring and autumn were around 20 %, and winter was around 5 %. On the other hand, the spatial features were region-dependent. The primary precipitation regime, summer–autumn–spring–winter, was located in central and eastern regions which were to the north of the Huaihe River, in eastern Tibet, and in western Southwest China. Another important regime, summer–spring–autumn–winter, appeared to the south of the Huaihe River, except in Jiangnan where spring precipitation dominated, and in the southeastern Hainan Island which was controlled by autumn precipitation.

In terms of the temporal change in the proportion of seasonal precipitation, the trends in the seasonal distribution of precipitation have changed over China as a whole since 1960. The proportion of winter precipitation has increased significantly, while those of the other three seasons have not shown any significant trends. On the regional scale, all the 11 geographic regions showed an increasing trend in the proportion of winter precipitation, which also agreed with trends for the whole of the country. The proportion of spring precipitation has decreased over the regions south of the Yellow River but increased elsewhere. The trend in the

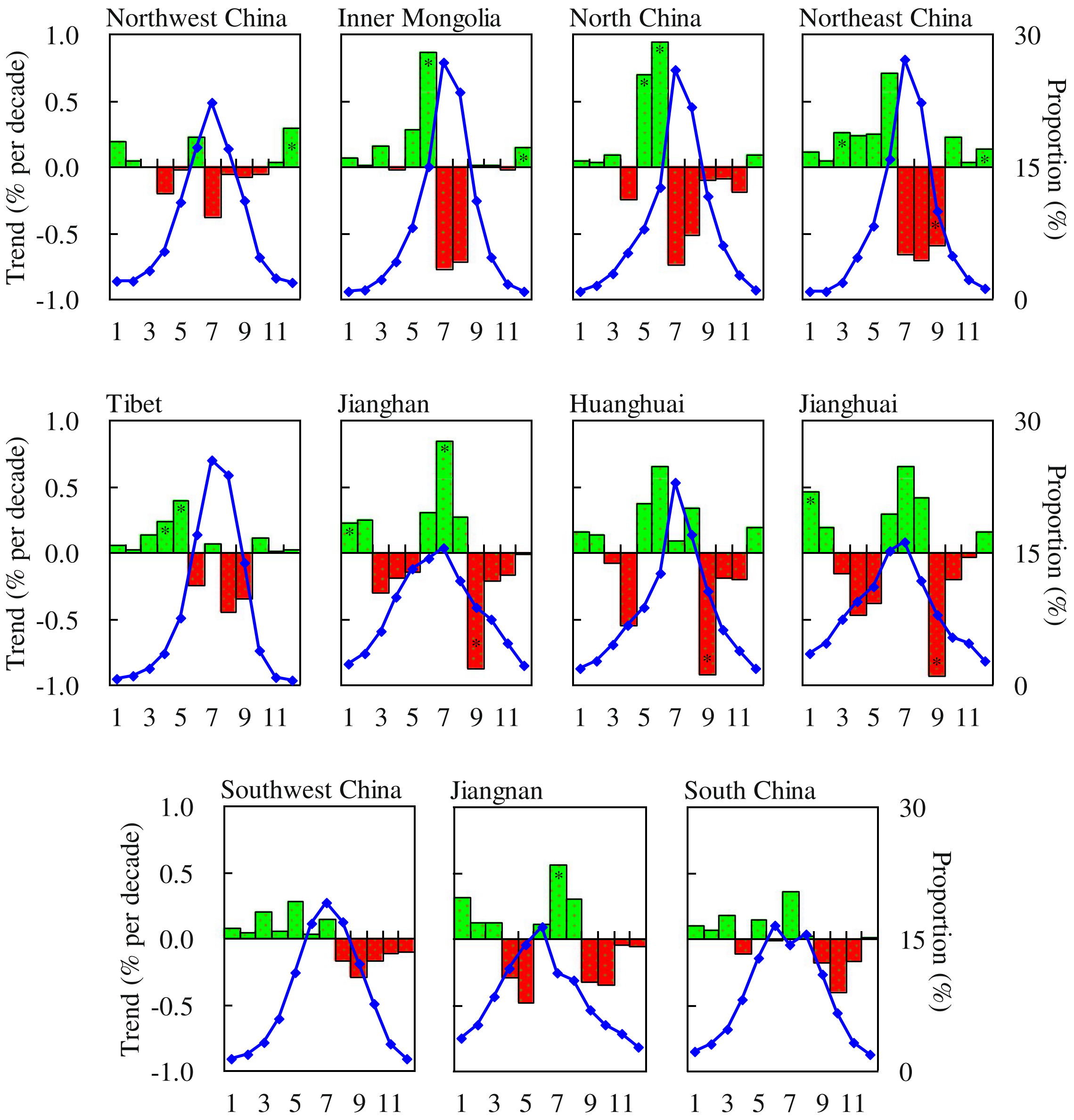

Fig. 6 Climatology and trends in the proportion of monthly precipitation for 11 regions in China. *Blue curves* signify climatologically monthly distributions. *Green* (*red*) *histograms* indicate increasing (decreasing) trends. *Asterisks* indicate the significant change at the 0.05 level

proportion of summer precipitation was generally opposite to that of spring. The proportion of autumn precipitation has decreased over the other ten regions except Inner Mongolia with no trend. On the interannual scale, the variability of precipitation seasonality was the largest in summer but the smallest in winter over China. On the decadal scale, China experienced a sharp decrease in the proportion of summer precipitation in the early 2000s. However, on the regional scale, it displayed a large interannual variability over North China, Huanghuai, and Jianghuai, and a large decadal variability over the other regions, especially over those regions south of the Yangtze River.

It should be noted that little attention has been given to the seasonality of precipitation over China, and hence, it is difficult to explain the present results from the perspective of cause and effect at this stage. Given that there have been some works about the mechanism of changes in seasonal precipitation amount over China, and that the proportion of seasonal precipitation was closely related to seasonal precipitation amount, we gave discussion in this aspect. For the proportion of summer precipitation, we revealed a rapid decrease in the late 1970s in South China and a rapid increase in the early 1990s in South China and Jiangnan, both of which were similar to the changes of summer precipitation amount (e.g., Li et al. 2004; Zhai et al. 2005; Ding et al. 2008; Deng et al. 2009). Accompanying these precipitation changes, large-scale atmospheric circulation in the East Asian monsoon region was reported to undergo

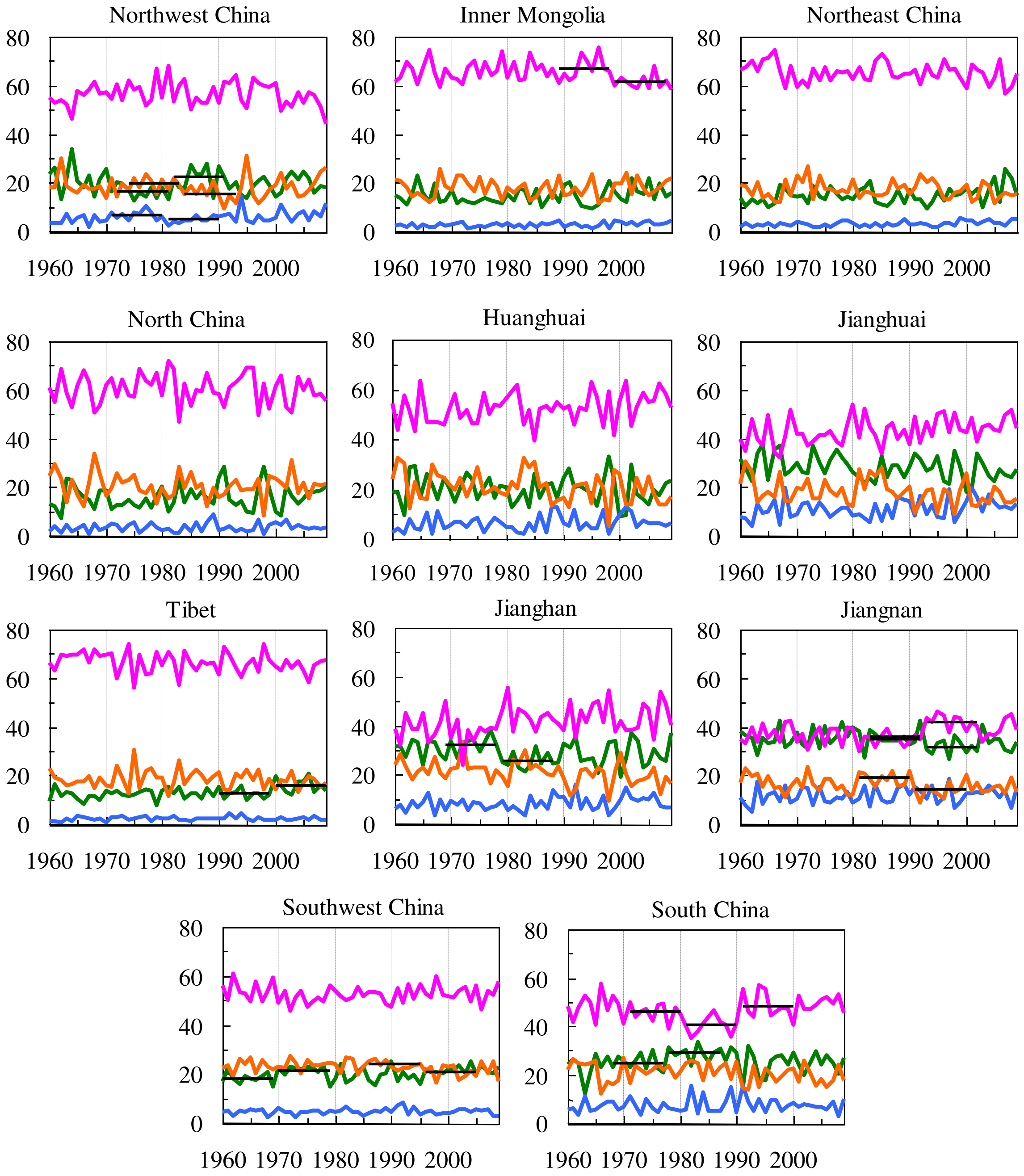

Fig. 7 Interannual and decadal variations in the proportion of seasonal precipitation during the period 1960–2009 for 11 regions in China. The *x*-axis represents the year, and the *y*-axis represents the proportion of seasonal precipitation (%). *Blue*, *green*, *pink*, and *orange lines* represent winter, spring, summer, and autumn, respectively. *Horizontal black solid lines* in the series indicate the periods before and after the climatic jumps, using MTT at the 0.01 significance level on the decadal scale

similar variations, including the weakening summer monsoon, the southward shift of the predominating upward motion zone from North China to the Yangtze River basin and South China, the change from the warming to cooling center in the upper troposphere in the Asian region, and the significant intensification and westward extension of the western North Pacific subtropical high (Wang 2001; Qian et al. 2003; Ding et al. 2008). For the other three seasonal precipitations, there were few studies. Li et al. (2010) pointed that the possible causes for the interdecadal change of the rainfall in China were closely related with the shift of the ascending and descending branches of the Hadley circulation, the intensification and migration of the westerly jet, the dry and wet conditions of atmospheric stratification, as well as the origin of water vapor. This explains the increase in the proportion of spring precipitation in South China but the decrease in the proportion of autumn precipitation in most parts of China, to a certain extent.

On the monthly scale, according to the research of Yu and Zhou (2007), the proportion of March precipitation over southern China increased in accordance with the strong upper-tropospheric cooling occurring in northeast Asia; in April and May, the proportion of precipitation over Jiangnan decreased, because the normal seasonal march of the monsoon rain band was interrupted following the southward extension and intensification of the upper-tropospheric cooling. In June, the proportion of precipitation over Jiangnan, Jianghuai, and Jianghan increased because of the northward migration of the rain band owing to the moderate upper-tropospheric warming and strong lower-stratospheric cooling over northeastern Asia; in July and August, the proportion of precipitation over Huanghuai and southern North China decreased, whereas it increased over Jiangnan, because the return of upper-tropospheric cooling weakened the northward progression of southerly monsoon winds. As yet, there has been very little published work on the mechanism of changes in the seasonal distribution of precipitation over China, and this calls for further studies.

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