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Rain-season trends in precipitation and their effect in different climate regions of China during 1961–2008

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Abstract

Using high-quality precipitation data from 524 stations, the trends of a set of precipitation variables during the main rain season (May–September) from 1961 to 2008 for different climate regions in China were analysed. However, different characteristics were displayed in different regions of China. In most temperate monsoon regions (north-eastern China), total rain-season precipitation and precipitation days showed decreasing trends; positive tendencies in precipitation intensity were, however, noted for most stations in this region. It is suggested that the decrease in rain-season precipitation is mainly related to there being fewer rain days and a change towards drier conditions in north-eastern China, and as a result, the available water resources have been negatively affected in the temperate monsoon regions. In most subtropical and tropical monsoon climate regions (south-eastern China), the rain-season precipitation and precipitation days (11–50, with >50 mm) showed slightly positive trends. However, precipitation days with ⩽10 mm decreased in these regions. Changes towards wetter conditions in this area, together with more frequent heavy rainfall events causing floods, have a severe impact on peoples' lives and socio-economic development. In general, the rain-season precipitation, precipitation days and rain-season precipitation intensity had all increased in the temperate continental and plateau/mountain regions of western China. This increase in rain-season precipitation has been favourable to pasture growth.

Keywords: precipitation, trend analysis, rain season, China

1. Introduction

Changes in total and extreme precipitation have attracted much attention in research as well from the general public during recent years. A large number of studies focusing on precipitation changes during the past 50–100 years have generally concluded that changes in precipitation extremes have occurred worldwide during the past century, associated with increasing mean temperatures (e.g. Trenberth 1999, Easterling *et al* 2000, Beniston and Stephenson 2004).

In their Fourth Assessment Report, The Intergovernmental Panel on Climate Change (IPCC 2007) presented a global synthesis of precipitation trends since 1900 based on the current knowledge. The general picture that emerged was significantly increased precipitation in eastern parts of North and South America, northern Europe and northern and central Asia, whereas drying has been observed in the Sahel region,

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the Mediterranean, southern Africa and parts of southern Asia.

The climate across China varies considerably and the country can be divided into several climate zones, which are mainly influenced by the Asian monsoon systems and the Tibetan Plateau (Domroes and Peng 1988, Ye and Gao 1979, Ding and Murakami 1994). Due to the large number of people living in the country, minor changes in the climate already have a profound impact on the people's livelihood. For instance, since Chinese agriculture is highly dependent on irrigation (48% of the cultivated area in 2006 was equipped with some kind of irrigation system (FAO 2011)), climate induced changes in the irrigation demand may have considerable impact on agricultural production (see e.g. Thomas 2008). Recent climate change and its various kinds of impact on, e.g., ecosystems, society, agriculture and water availability have therefore attracted much attention from a broad climate research community. There is, however, a constant need to monitor and analyse ongoing climate changes as new climate data become available.

The general aim of this study is to analyse ongoing precipitation changes in the rain season (May–September) using high-quality precipitation observations from 1961 to 2008, thereby providing an update of existing studies regarding precipitation variability across China. More specifically, the objectives of the paper are to analyse trends in the rain season of total precipitation, the number of days with light ($\leqslant$10 mm), moderate (11–50 mm) and heavy (>50 mm) precipitation, as well as precipitation intensity in different climate regions of China. The practical implications of changes in these parameters are also discussed, since many previous studies touch on this issue to a considerably lesser extent.

This letter is organized in the following manner. Section 2 provides climatological background information and section 3 briefly describes the data and methods. In section 4 the results are presented and section 5 links the findings to existing studies and discusses implications of changes in the rain season. Section 6 summarizes the main conclusions.

2. Background

In general, the rainy season occurs from May to September. It starts with a period of pre-monsoonal rain over South China in early April, and from May through August the summer monsoon rain belt moves northward to the Yangtze river basin (June) and finally to northern China (July). When the monsoon ends in August, the rain belt moves back to southern China. Due to the migration of the monsoon across China, the length of the rain season differs between southern and northern China, and rainfall amounts vary greatly among different regions depending on topography and distance to the ocean. In the subtropical and tropical monsoon climates of south-eastern China, annual rainfall amounts range from 1000 to 2000 mm. Here rice can grow in most regions. In the temperate monsoon climates of north-eastern China, annual rainfall amounts are considerably smaller, ranging from 400 to 800 mm, which is sufficient for growing corn, winter wheat and soya beans. Here, spring droughts are frequent, and as a result irrigation

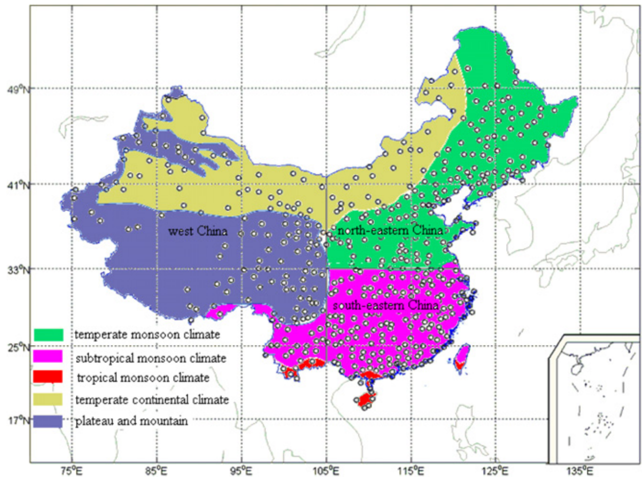

Figure 1. The distribution of climate regions in China and the locations of the 524 stations used in this study.

is necessary for agriculture during periods of drought. In the temperate continental climates, as well as the plateau and mountain regions, of western China, annual rainfall amounts are as low as 50–400 mm. Here, the vegetation ranges from forests to grasslands, and to deserts, depending on the humidity conditions (figure 1).

Besides the large variability in the spatial precipitation distribution, long-term changes in Chinese precipitation are evident (Ding and Sun 2003, Kripalani and Kulkarni 2001, Wang *et al* 1981, 2000, Zhai and Ren 1999, Zhao *et al* 2005, Ren *et al* 2000). Zhai *et al* (2005) analysed the trend in normalized annual precipitation anomalies as well as some annual extremes (daily precipitation >50 and >100 mm) for the period 1951–95 using 296 stations in China. While no obvious trends in the annual precipitation in China as a whole were found, the number of days with rainstorms (daily precipitation >50 mm) had decreased in northern China. These findings were later confirmed by Zhai *et al* (2005), using a larger station network (530 stations). Ren *et al* (2000) showed an increasing trend in summer precipitation over the middle to lower reaches of the Yangtze river, and a decreasing trend over the Yellow river basin, but virtually no change at higher latitudes. Examining the relationship between long-term summer precipitation change and the large-scale monsoon circulation features, Ding *et al* (2008, 2009) found that a significant weakening of the East Asian summer monsoon has led to reduced precipitation in North China. Shen (2010) studied 50 yr of water resource changes in different Chinese river basins, and found that rainfall had decreased in the Hai and Liao river basins as well as in parts of the Yellow river basin, while rainfall had increased in most regions in southern China, parts of northwest China and the northern part of northeast China. In addition, numerous studies have dealt with precipitation variability in specific regions, such as the Tarim river basin (Xu *et al* 2006, 2010), the Dongjiang river basin (e.g. Liu *et al* 2010) and the Pearl river basin (e.g. Zhang *et al* 2010).

3. Data and methods

3.1. Precipitation data

In order to investigate the change of rain-season (May to September) precipitation in different climate regions of China, a data set of daily precipitation, obtained from 740 stations, covering mainland China for the period 1961–2008, was used. It included almost all national climate stations, and was developed at the Climate Data Centre (CDC) of the China Meteorological Administration. Only station series with a low rate of missing data (⩽5%) were chosen, forming a subset of 524 stations that were found to be suitable and were subsequently used in the analysis (figure 1).

3.2. Statistical analysis

To assess the spatial and temporal distributions of rain-season precipitation changes in China, total precipitations, precipitation intensities and numbers of days with precipitation exceeding certain thresholds were calculated, from 1961 to 2008. Precipitation intensity is the amount of precipitation collected per unit time interval and is here defined as the total precipitation in the rain season divided by the number of precipitation days (with >0 mm) for individual stations. The precipitation days were subdivided into three groups depending on precipitation amounts, where ⩽10 mm characterizes light rain, 11–50 mm moderate rain and >50 mm heavy rain, according to the meteorological regulations of China. In China, daily rainfall >50 mm can induce breakage of reservoirs and, causing floods, lead to serious threats to people's safety and the economy (Li *et al* 2009a).

Changes in the total amount of rain-season precipitation may have different causes. They may be caused either by variations in the number of precipitation days or by variations in the precipitation intensity, or by both, and studying both factors gives possibilities for better understanding the individual contributions to changes in rain-season precipitation of these factors during the rainy season. For each precipitation variable, linear trends over time for the 1961–2008 periods were calculated for each climate station and the significance was tested using the Mann–Kendall trend test (Yue *et al* 2002).

4. Results

4.1. Rain-season total precipitation changes

The results from the trend analysis of total precipitation in the rain season are shown in figure 2. Averaged over all stations, a general increasing tendency in rain-season precipitation between 1961 and 2008 was seen, although large interannual variability is evident (figure 2(a)). The magnitude and sign of the observed trends varies across China (figure 2(b)). In general, a majority of the stations located in the temperate monsoon climate experienced decreasing rain-season precipitation trends, while in general they increased in the other climate regions.

In the regions west of 105°E, most stations showed tendencies, i.e. non-significant trends, for increased rain-season precipitation over the analysed period. Positive tendencies for rain-season precipitation were found at 68% of the stations (106 out of 156 stations). Furthermore, significant trends in rain-season precipitation, ranging from 18.9 to 355.9 mm, were found at 22% of the stations. The two largest significant trends appeared in the records of Jiali (30.66°N, 93.28°E) and Wudaoliang (35.22°N, 93.08°E) with linear significant increasing trends of 60.8% and 107.8% respectively.

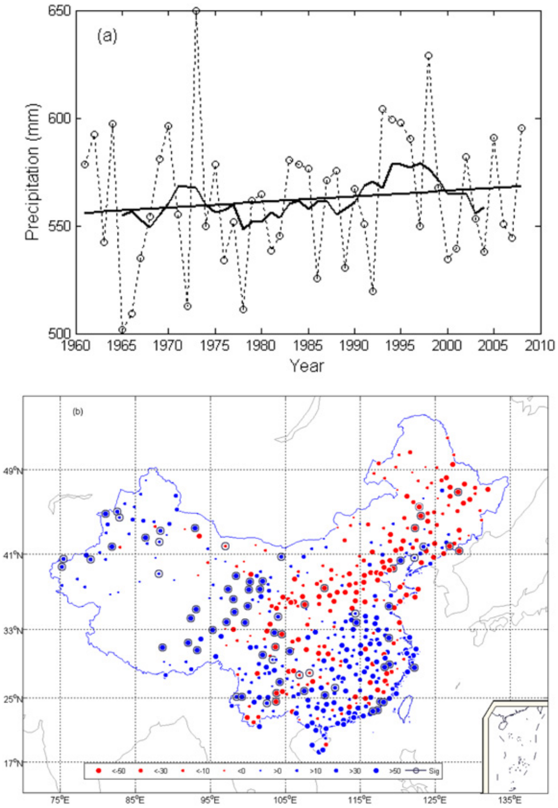

Figure 2. (a) Averaged time series of precipitation (mm) and (b) regional distribution of precipitation trends from 1961–2008 over China (mm). ((a) Dotted lines: interannual variability, solid lines: 9 yr moving average and trend line).

In south-eastern China, east of 105°E and south of 33°N, 57% of the stations (118 out of 177 stations) showed positive rain-season precipitation tendencies, while significant positive trends were only found at 3 stations (figure 2(b)). In north-eastern China, east of 105°E and north of 33°N, negative rain-season precipitation tendencies were found at 82% of the stations (157 out of 191 stations), and significant negative trends of precipitation were found at 13 stations (6.8%), ranging from −94.1 to −177.4 mm.

Overall, the total rain-season precipitation increased by 12.6 mm (2.2%) during 1961–2008 in the whole of China (change is non-significant). The general picture that emerges is a change towards a slightly wetter rain-season climate in western China, belonging to temperate continental and plateau/mountain climates, as well as large parts of the south-eastern part of the country (subtropical and tropical monsoon climate). During the same period the north-eastern regions, mainly belonging to the temperate monsoon climate, became drier.

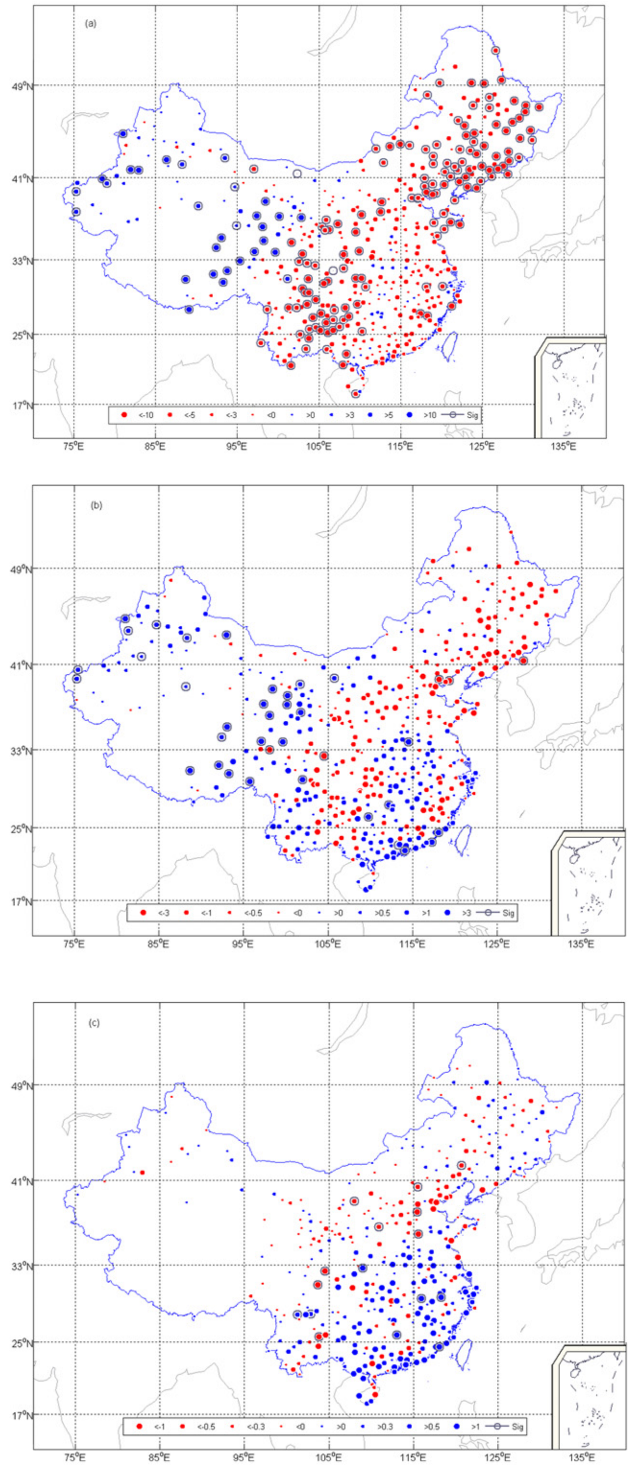

Figure 3. Change of precipitation days ((a) daily precipitation 0–10 mm, (b) daily precipitation 11–50 mm, (c) daily precipitation >50 mm) in the rain season from 1961 to 2008 over China.

4.2. Change in the number of rain-season precipitation days

The trends in the number of days with precipitation over a certain threshold (i.e. ⩽10, 11–50 and >50 mm) are shown in figure 3.

For China as a whole, the results indicate that the precipitation days with 0–10 mm decreased by 2.8 days from 1961 to 2008 (non-significant). There is a clear spatial pattern with decreasing number of precipitation days with ⩽10 mm in most of the regions in north-eastern and south-eastern China, while in western China, the number of rain days increased. In north-eastern China, the precipitation days with ⩽10 mm decreased considerably. Here 95.8% of the stations (number of stations) displayed negative tendencies, and 42.4% showed significant negative trends corresponding to a reduction of 6 to 19.2 days. In south-eastern China, 16% of the stations (28 stations) displayed significant negative trends, and 88.7% of the stations showed negative tendencies. In contrast, the precipitation days with ⩽10 mm increased in western China: 73% of all stations (156 stations) displayed positive tendencies, but only 18% of stations (28 stations) showed significant positive trends (figure 3(a)).

Figure 3(b) shows the trends in precipitation days with 11–50 mm. In total, they increased slightly by 0.1 days for the whole of China. Similar to the trends in precipitation days with ⩽10 mm, the precipitation days with 11–50 mm in western China increased to 66% of the 103 stations, the increase being significant at 16% of the stations (25 stations). In south-eastern China, 54% of the stations showed positive tendencies, with significant trends at 6 stations (177 stations), while the remaining stations displayed negative tendencies. In north-eastern China, precipitation days with 11–50 mm decreased at most stations (71.2%), but significant trends were only found at 3 stations.

The trends of precipitation days with >50 mm during 1961–2008 are shown in figure 3(c), where the results show an increase by 0.16 days for the whole of China. In western China, the rain-season precipitation is usually less than 400 mm, which results in very few days that are precipitation days with >50 mm. In south-eastern China, precipitation days with >50 mm increased by 0.41 days, and 70% of the 156 stations showed positive tendencies, significant at 5 stations. In north-eastern China, precipitation days with >50 mm decreased by 0.14 days, and most stations (61.8%) displayed negative tendencies, including 6 stations with significant negative trends.

Overall, the trends in precipitation days varied across China. In north-eastern China, precipitation days showed considerably decreasing trends; in particular, about a half of the stations displayed decreasing trends significantly for light rainfall (0–10 mm). In south-eastern China, the precipitation days with 0–10 mm also decreased, while the precipitation days with >50 mm increased considerably in most parts of the regions. In western China, the precipitation days increased significantly during 1961–2008. These results therefore indicate a decrease in light rainfall in northeast and southeast China, while heavy rainfalls have been increasing in most regions of south-eastern China.

4.3. Change of precipitation intensity in the rain season

A time series of precipitation intensity averaged for all 524 Chinese stations from 1961 to 2008 is shown in figure 4(a). The precipitation intensity increased significantly by, on average, 0.79 mm day^{-1}, but the increase was not continuous throughout the whole period. While there was a slight

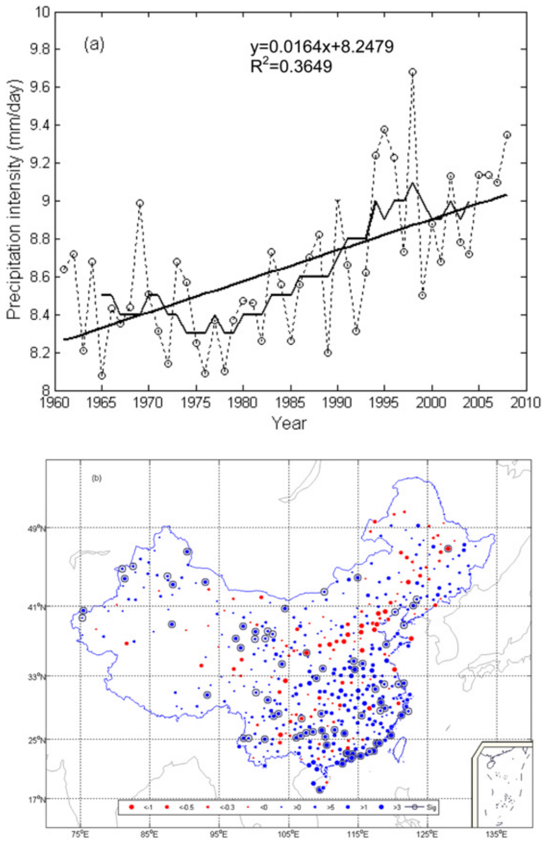

Figure 4. (a) Averaged time series of precipitation intensity and (b) regional distribution of precipitation intensity trends from 1961 to 2008 over China ((a) dotted lines: interannual variability, solid lines: 9 yr moving average and trend line).

decrease in precipitation intensity in the 1970s, an increasing trend started in the 1980s resulting in a precipitation intensity of about 9.0 mm day^{-1} during 2001–8 compared to about 8.3 mm day^{-1} in the 1970s.

The regional distribution of precipitation intensity trends in China from 1961–2008 is shown in figure 4(b). The precipitation intensity increased in western and south-eastern China, where 67.3% and 83.6% of the stations respectively displayed increasing tendencies. Out of these stations, 16.0% and 16.3% of the stations (for western and south-eastern China respectively) showed significant positive trends, from 0.9 to 6.2 mm day^{-1}. Positive tendencies in precipitation intensity were also noted for 61.8% of the stations in northeast China. These results indicate that, in general, precipitation intensity increased in the whole of China, especially in the south-eastern parts.

Regarding the relation between rain-season precipitation, precipitation days and precipitation intensity, it is clear that the increase in rain-season precipitation in the south-eastern regions of China is associated with more intense precipitation overcompensating for the rainfall deficit due to there being fewer rain days with $\leqslant$10 mm. The decrease in rain-season precipitation in north-eastern China is mainly related to there being fewer light rain days (with $\leqslant$10 mm) in combination with the decreased precipitation intensity. However, there are also stations in this region where precipitation intensity instead increased. This indicates that more intensive precipitation does not compensate for the rainfall deficit due to a decrease in the frequency of precipitation days with $\leqslant$10 mm. In western China the total number of precipitation days increased in accordance with positive trends in both precipitation intensity and precipitation days.

5. Discussion

5.1. Rain-season precipitation changes in China during 1961–2008

The results showed that the total rain-season precipitation had increased by 12.6 mm during the 48 yr period averaged over China (table 1). While the rain-season precipitation showed different trends in different regions, in western and south-eastern parts of China, the precipitation gave increased tendencies, while in north-eastern China, the precipitation showed decreased tendencies.

In western and south-eastern China, 67.9% and 57% of stations showed tendencies for increased precipitation respectively, where 22% of stations showed significant positive trends in western China, and 6.8% in southeast China. Gong and Ho (2002) pointed out that the summer rainfall (from June to August) over the Yangtze river valley (south-eastern China) had increased over the last few decades, which could be related to changes in the subtropical high over the Northwest Pacific. On the basis of data from China, Korea, and Japan, Qian *et al* (2003) suggested that increasing summer precipitation in southern China could be linked to the multi-decadal variation of the monsoon circulation in eastern Asia. Moreover, a weakening in the East Asian summer monsoon, accompanied by a southward shift in the major monsoon rain belt from northern to southern China, has been observed since the end of 1970s (IPCC 2007).

The results from most regions of temperate monsoon climate clearly indicated trends towards drier rainy seasons, where 82% of the stations showed tendencies for decreasing rain-season precipitation (figure 2). This result agrees with the findings of an apparent summer precipitation decrease in northern China during the past few decades (Chen *et al* 1991, Xu *et al* 1992, Chen *et al* 2005). This may be related to a significant weakening of the East Asian summer monsoon in the last decades, which has decreased the northward moisture transport, leading to a deficit in moisture supply for precipitation in northern China (Ding *et al* 2008).

The trends in precipitation days also varied among different climate regions. In north-eastern China, the temperate monsoon climate regions, the precipitation days analyses indicated that the number of days with light, moderate and heavy precipitation has decreased in most of the area. This is in agreement with the results of Wang *et al* (2006) who calculated the change in the number of rain days with >0 mm in China over the last 40 yr, and found a decreasing number of rain days in northern China. In western China, the region with the smallest number of rain days with >50 mm, those with $\leqslant$10 mm and 11–50 mm increased significantly, suggesting that the P_{RS} increase is partly due to the increase of light

Table 1. Linear trends of total precipitation, number of precipitation days and precipitation intensity of the rain season over the whole of China, and stations with significant trends in different climate regions from 1961 to 2008. (Bold: significant trends with $p < 0.05$, italic: stations with decreasing trends, black: stations with increasing trends.)

	Trends over the whole of China	Stations with significant trends in Northeast China (⩾105°E, ⩾33°N)	Stations with significant trends in Southeast China (⩾105°E, <33°N)	Stations with significant trends in western China (<105°E)
Total precipitation	12.6 mm, 2.2%	*13 stations, 6.8%*	**3 stations, 1.4%**	**35 stations, 22.4%**
Precipitation days with >0 mm	−2.8 days	*81 stations, 42.4%*	*28 stations, 15.8%*	**28 stations, 17.9%**
Precipitation days with >10 mm	0.1 days	*3 stations, 1.6%*	**6 stations, 3.4%**	**25 stations, 16%**
Precipitation days with >50 mm	0.16 days	*6 stations, 3.1%*	**5 stations, 2.8%**	—
Precipitation intensity	**0.79 mm day^{-1}**	**11 stations, 5.8%**	**29 stations, 16.4%**	**25 stations, 16%**

and moderate rain days. Fu *et al* (2008) also pointed that the days of light rain were increasing in number in western China during 1961–2005. In south-eastern China, the spatial distribution of precipitation day trends varies with precipitation intensity. Here, the precipitation days with light rainfall were clearly decreasing in number, while the precipitation days with heavy rain, often inducing floods, have increased in number. One implication of this change is that the risk for floods and droughts has increased in south-eastern China.

The precipitation intensity increased significantly by 0.79 mm day^{-1} over the whole of China in 1961–2008. Furthermore, this was reinforced in western and south-eastern China, which may lead to more floods in south-eastern China.

The observed precipitation changes are very likely to continue in the future due to global warming. According to the IPCC's Fourth Assessment Report (IPCC 2007) increasing summer precipitation and more extreme rainfall events, associated with tropical cyclone changes, are likely to occur in South East Asia. Since precipitation over South East Asia is strongly controlled by the strength of the Asian monsoon systems, any circulation changes here will have a considerable impact. Although global climate model (GCM) simulations project a weakening of the Asian summer monsoon circulation by the end of the 21st century, enhanced moisture convergence in a warmer atmosphere probably dominates over the weaker circulation, giving rise to enhanced precipitation. Also, Sun and Ding (2009), using the latest generation of coupled climate models, projected a reinforcement of the East Asian monsoon systems around the 2040s, which would mean that the precipitation over the whole of China would be increased.

5.2. Implications of rain-season precipitation changes

Changes in the precipitation conditions and characteristics during the rainy season have a direct impact on the hydrological cycle, as well as on the temporal and spatial distributions of rainfall across China. This in turn has a wide range of practical implications. Decreasing precipitation will have a considerable impact on the water availability for, e.g., agriculture, industrial production and drinking water demand, especially in regions where water resources are already limited. Increasing the total precipitation, together with an increased frequency of heavy rainfall events, on the other hand may cause repeated damage, e.g. due to flooding, mudflows or landslides. In addition, changes in the spatial and temporal distributions of rainfall across China affect the balance between water resources and demands. A number of socio-economic consequences related to precipitation changes in China are discussed below.

In northeast China, decreasing rain-season precipitation will have a strong impact on the water resources. During 1951–2000, about 40% of the total 10 000 km of rivers had been changed from having runoff throughout the year to seasonal runoff. During the same time the averaged annual inflow to the Pacific Ocean decreased by 80% compared to the 1950s. Furthermore, compared to the 1950s, wetland areas decreased from 10 000 to 1000 km^2 in northeast China (Jia *et al* 2002). On the basis of a study of the groundwater level from a network of 600 shallow groundwater observation wells in Hebei, a province of Northeast China, Liu *et al* (2001) pointed out that the average depth of the groundwater had, on average, decreased from 7.23 m in 1983 to 11.52 m in 1993, yielding a decline of 0.43 m yr^{-1}. This was partly related to the decreased precipitation amounts during the rainy season.

Changes in water resources and surface hydrology are a result of the combined effects involving climate changes and various human activities. To what degree the examples mentioned above are caused by climate variability and/or various human activities is hard to estimate. Shen (2010) mentions that landscape changes alter the rainfall–runoff relationship, which may result in considerable reductions in water resources. This has been observed in major Chinese river basins over the past 50 years. In an attempt to separate the impact of climate change and human activities on runoff in the Dongjian river basin, Liu *et al* (2010) found that they separately accounted for approximately 50% of the runoff changes during the low-flow period. However, Li *et al* (2009b) found that climate variability had a stronger impact than land use changes when studying the surface hydrology of the Heihe catchment on the Loess plateau.

In the subtropical and tropical monsoon climate regions of China, precipitation often exceeds 1000 mm during the rainy season and floods occur frequently. The total rain-season precipitation, and the number of precipitation days with >50 mm as well as precipitation intensity showed positive trends, which have induced more floods. As a result, people's lives and socio-economic development have been strongly influenced by the increase in heavy rainfall events as well as occasions with floods and mudslides. For example, Ye *et al* (2009) found that the flood days had been increasing in number since the 1990s in Hubei and Chongqing, provinces of south-eastern China. The data provided by the Ministry of Agriculture of China showed that the crop land affected by floods was 282.9 kha and 274.5 kha in the 1960s and 1970s respectively in southern China, while it amounted to 703.2 kha in the 1990s and 459.5 kha in 2001–8 (www.moa.gov.cn/). Also, mudslides related to floods have had a significant impact on people's welfare. For instance, a heavy downpour occurred on 13 June 2006 in Wangmo, a county in southern China, where the precipitation amounted to 196 mm in 4 h, and the results of this event included a mountain flood where 30 people died and 24 people went missing (NCC 2006, 2008). Moreover, heavy rainfalls also have an impact on the socio-economic activities in urban areas. The accelerated urbanization in China went hand in hand with increasing population and decreasing vegetation coverage. The urban rainwater discharges mainly through underground pipelines, and during heavy rainfall events, the drainage capacity of these underground pipelines is not sufficient, frequently causing floods within urban areas. For instance, Shanghai, the largest city of southern China with a population of 19.2 million, was hit by very heavy rainfall on 25 August 2008 receiving 117.5 mm in 1 h. The downpour produced a rainwater volume that exceeded the city's drainage capacity and as a consequence more than 150 roads were deeply inundated with water at a maximum depth at 1.5 m. As a consequence, numerous roads were closed for 10 h, and 138 flights were delayed (NCC 2008). At present, most Chinese cities are applying heavy rainfall prevention standards developed 30 years ago, and they cannot rapidly adapt to changed climate conditions. The results of our investigation point towards the need to include heavy rainfall extremes into the prevention standards when these cities are rebuilt, to be able to cope with changed climate conditions.

In temperate continental climate regions as well as plateau and mountain climate regions of China, the climate is rather dry, and vegetation varies from forests to grasslands, and to deserts. An increase in the total precipitation and number of precipitation days as well as precipitation intensity in this area is considered as favourable for growing pasture.

6. Conclusions

China, a large developing country, is dominated by tropical and subtropical monsoon climates in the south-eastern area, a temperate monsoon climate in the north-eastern area, as well as plateau and mountain climates in the west. Using high-quality precipitation data from 524 stations over China, the trends of total precipitation, number of precipitation days (with 0–10, 11–50 and >50 mm) and precipitation intensity during the rainy season were analysed, from 1961 to 2008.

Averaged over the whole of China, the results showed that total rain-season precipitation had increased by 12.6 mm, and the numbers of precipitation days with 11–50 mm and >50 mm were increased slightly, by 0.1 days and 0.16 days respectively, while the precipitation intensity had increased significantly by 0.79 mm day^{-1} during the 48 yr period. The precipitation intensity has increased across the whole of China, especially in south-eastern China, but deviations from this general trend were found depending on region and rainfall statistics.

In most temperate monsoon regions, east of 105°E and north of 33°N, total rain-season precipitation has been decreasing during 1961–2008; furthermore, the number of precipitation days with $\leqslant$10, 11–50 and >50 mm all showed decreasing tendencies for most stations, and the number of precipitation days with $\leqslant$10 mm experienced significant negative trends at 42.4% of 191 stations, while positive tendencies in precipitation intensity were noted for most stations in northeast China. These results indicate that the decrease in total precipitation in north-eastern China is mainly related to there being fewer rain days. As a result, the water resources in temperate monsoon climate regions have been strongly influenced, since river runoff and water reservoirs are mainly fed from rainfall during the rainy season. Because 42% of the total arable area needs irrigation in the temperate monsoon climate regions, any change towards drier conditions will have a strong impact on the water demand in agriculture.

In most regions characterized by subtropical and tropical monsoon climate in China, east of 105°E and south of 33°N, the total number of days and number of precipitation days (11–50, with >50 mm) showed positive trends. Moreover, the precipitation intensity showed significant increasing trends at 16.3% of the stations, possibly inducing more floods. Changes towards wetter conditions in this area, together with more frequent heavy rainfall events causing floods as well as mudslides, will severely impact people's lives and socio-economic development. This is obvious from several extreme events that have occurred during the past few years.

In most of the temperate continental regions, as well as the plateau and mountain regions, of China, west of 105°E, the total rain-season precipitation, the number of precipitation days and the precipitation intensity have all increased. Here 22.4% of stations showed significant increasing trends for P_{RS}, ranging from 18.9 to 355.9 mm, which is considered as favouring pasture growth.

Acknowledgments

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