Long and short duration heavy rainfall spatio-temporal patterns change and its contribution to total heavy rainfall in China

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Abstract. Recent studies have noted a worldwide increase in the occurrence of extreme-precipitation events. Here we use daily rainfall data from 1951 to 2010 of 659 meteorological stations in China and on the basis of duration days defined long duration heavy rainfall. Results indicate that: on the spatial distribution, short duration heavy rainfall shows gradually decreasing phenomenon from the southeast coastal to northwest inland in China from 1951 to 2010. And long duration heavy rainfall is concentrated in the southeast coastal areas, such as Guangdong, Guangxi and Hainan. On the temporal change, the interannual and interdecadal short and long duration heavy rainfall both show increasing trend. In precipitation contribution ratio, the proportion of total heavy rainfall amounts to total rainfall amounts and total heavy rainfall days to total rainfall days are 6.1%~27.7% and 0.6%~27.7% respectively from 1951 to 2010 in China. Short duration storm to occupy the dominant position that the proportion of short duration heavy rainfall amounts to total heavy rainfall amounts and short duration heavy rainfall days to total heavy rainfall days are 75.9%~89.4% and 75.6%~89.4% respectively in the same period. Long duration heavy rainfall occupy a secondary position that the proportion of long duration heavy rainfall amounts to total heavy rainfall amounts and short duration heavy rainfall days to total heavy rainfall days are only 10.6%~24.1% and 10.8%~24.4% respectively. On the trend of precipitation contribution, China's the contribution rate of total heavy rainfall to the total rainfall show increasing trend with contribution of rainfall amounts and rainfall days trend are 2.1%/10a and 0.2%/10a respectively. The contribution rate of short duration heavy rainfall to the total heavy rainfall show increasing trend with contribution of rainfall amounts and rainfall days trend are 0.5%/10a and 0.4%/10a respectively. On the contrary, the contribution rate of long duration heavy rainfall to the total heavy rainfall show decreasing trend with contribution of rainfall amounts and rainfall days trend are -0.5%/10a and -0.4%/10a respectively. The results suggest that the precipitation in China are changing to extremely accompanied by short duration storm increased significantly.

1. Introduction
As global climate changing, the increase of extreme precipitation events has led to serious urban floods and far-reaching impacts on urban sustainable development [1-3]. Storms and floods are often closely related to extremely heavy precipitation events in a short period of time. The temporal and spatial distribution of short-duration extreme precipitation is well correlated with flood disasters [4, 5]. Studies have shown that changing climates lead to changes in frequency, intensity, spatial distribution, duration and time of occurrence of extreme precipitation events; It is high reliability that, economic losses...
connected with weather and climate hazards are increasingly [6]. At present, the observation results at home and abroad suggest that, as the global warming, the number of short-duration extreme precipitation increase may be greater than extreme precipitation over long periods of time, that is, global warming causes surface evaporation to increase, resulting in increased atmospheric water retention capacity, global and regional water cycle is accelerated, which will inevitably lead to an increase in precipitation in some areas [4-7], in which the increase of short-duration convective precipitation is greater than that of long-duration stratified precipitation [8]. Observational evidence since 1950 suggests that there may be more areas with a significant increase in the number of extremely heavy precipitation events on a global scale [9]. IPCC AR5 pointed out that when the greenhouse gas CO2 doubles, the extreme precipitation will be significantly increased, and its amplitude is much larger than the precipitation of average intensity [6]. With the climate changing, the trend of total precipitation in China's national scale is not obvious, but the intensity of rainstorms is increasing [10-12], and the areas suffering from abnormally heavy precipitation events are also increasing [13,14]; However, China's rainstorms in different periods show significant regional differences. Therefore, it is necessary to study in depth the intricate spatial and temporal characteristics of different torrential rains and their role in the overall precipitation process.

The duration of the storm is an important indicator of the characteristics of the rainstorm. Different duration rainstorms may be the result of the weather systems effects with different time scales, and generally they have different physical mechanisms. Since short-duration precipitation may be closely related to solar radiation heating, it is mostly a product of strong convective weather. Generally, the rainfall intensity is relatively large, but the duration is short. In the afternoon of urban areas, convective activities develop strongly, and short-lived rain events with strong intensity often occur. Long-duration heavy rain is generally a result of the weather system process, which changes with the development of the weather process, and thus has a relatively long duration. In the study of precipitation over time, some scholars have reduced the overall water loss in the warm season (May to September) in eastern China to long-duration (>6 hours) and short-duration (1~3 hours). The spatial distribution of short-duration precipitation ratios varies greatly, so it is speculated that the generation of different durations of precipitation may be results of different physical mechanisms. Different durations of precipitation often have distinct temporal and spatial distribution characteristics. Studying the storms in different durations not only can explore the temporal and spatial variation characteristics of Chinese storms from a new perspective, but also bring new ideas to the study of the mechanism of heavy rain.

As mentioned above, this paper conducts in-depth research on the temporal and spatial variation pattern of short and long-duration rainstorms in China from 1951 to 2010 and its impact to total heavy rainfall, and a scientific basis for the prevention of flood disaster risks in Chinese cities is provided.

2. Data and methods

2.1. Data Sources
In this paper, the precipitation data used comes from the daily weather data database of the China Meteorological Science Data Sharing Service Network. According to the principle of keeping the most sites as much as possible and ensuring the continuous observation time, the relevant data is checked and filled, the filling rate is less than 5%, and finally 659 available precipitation observation stations are obtained.

2.2. Calculation method
According to the daily precipitation data used, the daily rainfall reaches 50 mm is set as the storm threshold, then the short duration rainstorm is defined as the rainstorm event lasting only 1 day; the long duration rainstorm is defined as rainstorm event lasting 2 days and above. According to the above definition of short and long duration rainstorm, this paper calculates the storm duration, rainy day and rain intensity of short duration and long duration from 1951 to 2010, and the long-duration trend of diagnosis of short duration and long duration rainstorm from 1951 to 2010. The proportion of the total
rainstorm. The calculation method of storm rainfall, rainy day and rain intensity is detailed in the literature [14].

3. Results and analysis

3.1. Temporal and spatial changes in China's short duration and long duration rainstorm

From the perspective of spatial changes, China's interdecadal short-duration rainfall has continuously increased from the 1950s. The spatial distribution of heavy rains exceeding 4000 mm has been expanding, which has expanded from the south-eastern coastal areas to the north-western inland areas. In 1951-1960, the total amount of heavy rain in most sites in China was below 1000 mm, and most other sites were between 1000 and 4000 mm. From 1961-1970, the sites with more than 4000 mm began to increase in spatial distribution. The increased areas are mainly concentrated in coastal areas such as Guangdong, Guangxi, Hainan, Zhejiang, Hunan and the middle and lower reaches of the Yangtze River with relatively high urbanization level. From 1971 to 1980, the sum of the interdecadal short-duration storms from the Shandong Peninsula to the southwestern part of Guangxi was more than 1000 mm, and the sites with more than 1000 mm began to increase in space, especially in Guangdong, Guangxi, Hainan and other regions, which spatial distribution has increased significantly. From 1981 to 1990, the annual interdecadal short-duration storm rainfall at the east area the line from the Shandong Peninsula to of Guangxi’s southwestern have exceeded 1000 mm, and the majority exceeded 2000 mm. From 1991 to 2000, the annual interdecadal short-duration storm rainfall at the east area the line from the Shandong Peninsula to of Guangxi’s southwestern was almost over 2000 mm, and more than 4000 mm meteorological stations continued to expand into the northwest inland. Until 2001-2010, the annual interdecadal short-duration storm rainfall at the east area the line from the Shandong Peninsula to of Guangxi’s southwestern has almost all exceeded 3000 mm, and the stations with interdecadal short-duration storms exceeding 4000 mm further extended to the northwest. From 1951 to 2010, the annual interdecadal short-duration storm rainfalls in the north-western inland meteorological sites remained below 1000 mm. Compared with the interdecadal short-duration rainstorms in China, the interdecadal long-duration heavy rains in China has not shown a process of expanding from the southeast coast to the northwest inland, and the interdecadal long-duration rainfall is increasing. The number of stations in the interdecadal short-duration storm rainfalls of 1000-2000 mm, 2000-3000 mm, and 3000-4000 mm showed signs of increase and decrease during the period from 1951 to 2010. The number of sites with more than 1000 mm and less than 2000 mm is mainly concentrated in the middle and lower reaches of the Yangtze River in areas with plum rain season. The interdecadal long-duration rainfall in other regions was mostly less than 2000 mm in all periods from 1951 to 2010.

From the perspective of changes in the number of stations, the number of stations with an interdecadal short-duration storm less than 1000 mm in China has been reduced from 428 in 1951-1960 to 365 in 2001-2010; the most significant station reduction period is 1951-1970, which reduction rate was 9.87%; the number of stations with annual interdecadal short-duration storm rainfalls of 1000-2000 mm, 2000-3000 mm, and 3000-4000 mm showed signs of increase and decrease during the period from 1951 to 2010. The number of sites with 3000-4000 mm rainfalls increased significantly; the number of stations with annual interdecadal short-duration storm rainfalls of 1000-2000 mm increased significantly between 1951 and 2010, which had an increase of 6.53%. The most significant increase period was between 2001 and 2010, which shows that annual interdecadal short-duration storm rainfalls has been increasingly concentrated in the range of more than 4000 mm, further showing that the increase in the interdecadal short-duration storm rainfall is increasing. The number of stations in the interdecadal short-duration rainstorm days also showed a similar increase trend in different years from 1951 to 2010, but the number of stations with interdecadal short durations of heavy rain and rain was not changed in different ages, and the Chinese interdecadal duration Compared with the short-duration storm rainfall, the number of storms in each grade has not changed much from 1951 to 2010. The number of stations with an interdecadal long duration of less than 500 mm is dominant, accounting for
77.39%–86.19% of the total number of stations. The ratio of the number of stations larger than 500 mm to the total number of stations is 13.81%–22.61%. The number of stations larger than 2000 mm accounts for only 2.12% to 3.79% of the total number of stations. There are similar patterns in the changes in the number of stations in China during the epoch-making rainstorm days and heavy rains and rains.

From the perspective of time changes, China's interannual short-duration storm rainfall, rainy days and rain intensity show an overall increase trend in fluctuations, and the segmental characteristics of the trend change are consistent with the annual total storm rainfall, rainy days and rain intensity. The correlation coefficients of the interannual short-duration storm rainfall, rainy day and rain intensity with the interannual total storm rainfall, rainy day and rain intensity were 0.99, 0.99 and 0.64 \((n=60)\), respectively, and all passed the test of 0.01 significance level. From the perspective of interdecadal changes, China's interdecadal short-duration storms, rainy days and rain intensity are as consistent with the total interdecadal storms, rainy days and rains, which show a consistently increasing trend; In the piecewise time variation, they present the characteristic of “increase, and then stabilize, then increase rapidly”. Among them, the short-duration rainstorm, rainy days and rain intensity from 2001 to 2010 increased by 76.4%, 66.3% and 21.4%, respectively compared with the 1951-1980s. China's interannual long-duration heavy rainfall, rainy days and rain intensity showed an overall increasing trend in the fluctuations, but after 1965, the interannual long-duration rainstorm, rainy days and rain intensity all showed a slight decreased trend. The correlation coefficients of the annual interannual rainstorm, rainy day and rain intensity and the annual total storm rainfall, rainy day and rain intensity were 0.75, 0.74 and 0.62 \((n=60)\), respectively, and all passed the test of 0.01 significance level. Judging from the interdecadal changes, China's interdecadal long-duration rainfall, rain and rain intensity are not the same as the interdecadal total storm rainfall, rainy days and rain intensity, and do not show a consistent trend of increasing consistency, but rather great volatility.

3.2. Changes in the contribution of heavy rains to total rainfall in China

To examine the correlation between the long-term change trend of total rainfall and rainstorm in China, we compared China's interannual and interdecadal total rainfall, rainy days and rain intensity with China's interannual and interdecadal storms, rainy days and rain intensity. The results show that the interannual and interdecadal total rainfall, rainy days and rain intensity in China show a trend of increasing firstly and then decreasing, although the interannual and interdecadal total rainfall in China has increased since 1991-2010, but the increase is small. It is worth noting that China's interannual and interdecadal storms, rainy days and rain intensity have been showing an increasing trend. Especially between 1991 and 2010, China's interannual and interdecadal total rainfall and rainy days showed a decreasing trend. China's interannual and interdecadal storms and rainy days still showed an increasing trend during the same period, indicating China's interannual and interdecadal light rain rainfall and frequency have a tendency to decrease. To a certain extent, this indicates that China's precipitation is developing in the direction of extremes, that is, light rain is decreasing and heavy rain is increasing.

What's more, from the ratio of China's interannual storm rainfall and rainy days to total rainfall and rainy days, the proportion of China's interannual storm rainfall to total rainfall has increased year after year, with a linear increase trend of 1.8% per 10 years. From 6.1% in 1951 to 27.7% in 2010, the increase was 21.6%, an increase of 355.4%; the proportion of China's interdecadal rainstorm days to total rainfall days also increased with the year, linear increase trend It was 0.1% per 10 years, rising from 0.6% in 1951 to 2.5% in the 2010, an increase of 1.9%, an increase of 295.2%. It is particularly noteworthy that since 1990, the ratio of interannual storm rainfall and rainy days in China to total rainfall and rainy days has increased rapidly. Intermittent storm rainfall and rainy days account for the interannual total rainfall and rainy days, respectively. 2.1% per 10 years and 0.2% per 10 years. Judging from the interdecadal rainstorms and rainy days in China, the proportion of interdecadal rainstorms to total rainfall has increased with the chronology, which is 15.9% from the 1951s to the 1960s. It rose to 26.0% in the 2001-2010 period, an increase of 10.1%, an increase of 63.0%; the proportion of China's interdecadal rainstorms and rainy days as the total rainfall days also increased from 1.7% in 1951 to the 1960 rose to 2.4% in 2001-2010, with an increasing range of 0.7%, an increase of 44.0%. China's interannual and
interdecadal torrential rains accounted for an increasing trend in the proportion of total rainfall, especially since 1990, which is consistent with the above-mentioned comparative analysis of Chinese heavy rain and total rainfall. Therefore, it has also proved that the rainstorm in China has increased significantly, and precipitation is developing in the direction of extremes.

3.3. The contribution of China's short-duration-long-time heavy rain to the total rainstorm

From the perspective of the interannual short-duration and long-duration heavy rains accounting for the interannual total torrential rain, the interannual short-duration rainstorm and rainy days dominated, with the range of 75.9%–89.4% and 75.6%–89.2% respectively; The long-duration heavy rainfall and rainy days are in a minor position, with ranges ranging from 10.6% to 24.1% and 10.8% to 24.4%. From the perspective of long-duration trends, the interannual short-duration rainstorms and rainy days accounted for an increase in the proportion of total rainstorms and rainy days, with linear trends of 0.5% per 10 years and 0.4% per 10 years, respectively. The interannual long-duration rainstorm rainfall and rainy days accounted for a decreasing trend of total storm rainfall and rainy days, with linear trends of -0.5% per 10 years and -0.4% per 10 years, respectively. The above analysis shows that short-duration torrential rains dominate the torrential rain. Although the amount of interannual short duration and long duration torrential rain is increasing, the absolute increase amount of short-duration torrential rain is large, and the absolute increase amount of long-duration torrential rain is small. Judging from the ratio of interdecadal short-duration torrential rains and long-duration torrential rains to interdecadal torrential rains, the interdecadal short-duration torrential rains accounted for a large proportion of the total torrential rains, which takes the dominated position, and the proportion of the interdecadal long-duration torrential rains accounted for a small proportion of the total torrential rains, which takes the minor position.

4. Conclusion and discussion

4.1. Conclusion

(1) In terms of spatial distribution, China's interdecadal short-duration rainstorm rainfall is similar to the spatial distribution of total storm rainfall, that is, from 1951 to 2010, it gradually develops from the southeast coast to the northwest inland. The regions with long periods of heavy rain and heavy rainfall are mainly concentrated in coastal areas such as Guangdong, Guangxi, Fujian and Hainan. In the change of the number of heavy rainfall and rainfall stations, the number of stations with interdecadal short-duration rainstorms greater than 4000 mm and less than 1000 mm showed an increase and decrease trend respectively. In 2001-2010, compared with the 1951-1960, the increase and decrease were 42.5% and 33.1%, respectively. The number of sites with long-duration chronological storms has changed relatively small between 1951 and 2010.

(2) In terms of time change, China's interannual and interdecadal short-duration rainstorms showed an increasing trend. The short-duration rainstorms, rainy days and rain intensity in the 2001-2010 increased by 76.4%, 66.3% and 21.4% respectively compared with 1951-1960. Compared with the short-duration torrential rain, the long-duration rainstorm rainfall showed an increasing trend with larger fluctuations. Particularly, it is noteworthy that in terms of rainfall magnitude, the magnitude of China's short-duration storm rainfall is much larger than that of long-duration storms.

(3) In the contribution of total rainstorm to total rainfall, from the interannual variation, the ratio of annual interannual total rain rainfall to interannual total rainfall and rainfall increased from 6.1% in 1951 to 27.7% in 2010, with a linear increase trend of 1.8% per 10 years. The ratio of total annual rainstorm days to total rainfall days increased from 0.6% in 1951 to 2.5% in the 2010s, and the linear increase trend was 0.1% per 10 years. From the interdecadal changes, the ratio of interdecadal rainstorm to total rainfall increased from 15.9% in the 1951-1980s to 26.0% in the 2001-2010 period, an increase of 10.0%, an increase of 63.0%; inter-decadal storms the proportion of daily rainy days has also increased with the passage of the age, from 1.7% in the 1951-1980s to 2.4% in the 2001-2010 period, an increase of 0.7%, an increase of 43.98%. Through the comparative analysis of total rainstorm and total rainfall, it is found
that China's total rainfall first rises and then falls, while China's total torrential rain continues to increase, indicating that the light rain is decreasing, and China's precipitation is changing in the direction of extremes.

(4) In the short-duration and long-duration heavy rains contributing to the total rainstorm, China's interannual short-duration storm rainfall and rainy days dominated the total storm rainfall and rainy days, with the proportions ranging from 75.9% to 89.4% and 75.6% to 89.2%, respectively. The proportion of long-duration rainstorm and rainy days is relatively small. From the long-duration trend, the interannual short-duration rainstorm and rainy days accounted for an increase in the proportion of total rainstorm and rainy days, with linear trends of 0.5% per 10 years and 0.4% per 10 years, respectively. The interannual long-duration rainstorm rainfall and rainy days accounted for a decreasing trend of total storm rainfall and rainy days, with linear trends of -0.5% per 10 years and -0.4% per 10 years, respectively.

4.2. Discussion
High resolution storm data validation. Due to data limitations, domestic rainwater data from the perspective of meteorological climatology using hourly precipitation data and higher resolution precipitation data is less than abroad. Data with higher time resolution can provide characteristics such as duration and intensity of heavy rain, which is of great significance for understanding the temporal and spatial changes of heavy rain. The impact of heavy rain is often closely related to the duration of the rainstorm event. Using higher resolution data can more accurately describe the temporal and spatial variation characteristics and impact of heavy rain in China.

Multi-regional comparative analysis of different torrential rains. For the whole of China, the duration and intensity of heavy rains in different regions are not consistent, and the internal mechanism of the short-duration rainstorms in most regions is still unclear. In particular, the diachronic characteristics of summer rainstorms in different regions are different, and different durations of rainstorms have different interannual and interdecadal variations. Therefore, in the future, further research on different periods of heavy rain in different regions can be carried out.

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