Typhoon Impacts on China's Precipitation during 1957–1996

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ABSTRACT

Tropical Cyclone (TC) activity is an important feature of China's climate that can have important impacts on precipitation and can cause extensive property damage. In particular, precipitation from TCs contributes a significant portion of overall precipitation. This study deals with typhoons that influence China and focuses on their impact on China's precipitation. Four aspects are examined in this research. Firstly, the study of influencing typhoon frequency reveals that the main season that typhoons affect China is from May to November, especially between July and September. The frequency of influencing typhoons was steady during the past 40 years. Secondly, inspection of the climatology of station typhoon precipitation shows that Hainan and the southeastern coastalmost regions are most frequently affected by typhoons, and most of the regions south of the Yangtze River are affected by typhoons each year. Meanwhile, during 1957–1996, most of the typhoon-influenced regions show decreasing trends in typhoon precipitation but only the trends in southern Northeast China are significant. Thirdly, examination of the typhoon cases shows that there exists a significant linear relationship between the precipitation volume and impacted area. Finally, study of variations of typhoon impacts on China's precipitation suggests that there exists a decreasing trend in the contribution of typhoon precipitation to overall precipitation, while total annual volume of typhoon precipitation decreases significantly during the period.

Key words: tropical cyclone, influencing typhoon, typhoon frequency, typhoon precipitation

1. Introduction

Tropical cyclones (TCs) constitute one of the most destructive natural disasters that affect many countries around the globe and exact tremendous annual losses in lives and property. Each year about 80 large-scale, severe storms—TCs, hurricanes, and typhoons—occur throughout the world. The average annual damage has been estimated at about US $ 1500 million and the average annual death toll over the period 1947–1980 is about 15 000 persons (WMO 1995).

The western North Pacific (WNP), where an intense TC is commonly called a typhoon, is the site of the most numerous and violent TCs in the world, 36% of the annual average globally. For the convenience of description in this paper, without particular statement, typhoon refers not only to TCs but also to the extratropical cyclones into which TCs transform. General characteristics of TCs and the relationships to ENSO and QBO are revealed through climatological analyses of their spatial distributions and temporal variation. Chan (1985) found these two spectral peaks apparent in all studied time series. One corresponds to the generally accepted Southern Oscillation with a period of 3 to 3.5 years and the other to the quasi-biennial oscillation frequency. In another study, Chan (1995) revealed that to a certain extent, the stratospheric QBO also affects TC activity in WNP. Both the results of Landsea et al. (1996) and Chan and Shi (1996) suggest that total global TC activity most likely remains relatively steady.

A recent study by Chen et al. (1999) focuses on the climatic characteristics of TC activity in WNP. The results showed that the TC frequency is obviously higher during 1960–1972 than any other period. Seasonally, the frequency is highest from July to September, while it is the lowest during spring. There are three main cyclone genesis source regions, the South China Sea, the sea around the Philippine Islands and the sea around Malaysia.

Each year, China is influenced to different extent by each typhoon. Both landfalling typhoons and those passing offshore can influence China's weather and climate. The objective of this research is to study the impact of typhoons on China's precipitation both in terms of its climatology and any secular variation over the period.

2. Data and analysis

The western North Pacific typhoon track data used in this study includes two datasets. The first dataset (D1) is from the Shanghai Typhoon Institute, which contains the 6 hourly positions of each typhoon case during 1949–1996. The second dataset (D2) is from the U.S. National Weather Service, which includes irregular hourly positions of each case from 1945 to the present.

The two datasets are combined to build a historical dataset of 6 hourly observations as D1. Considering that when a typhoon track is over or close to China, D1 is relatively accurate. Then the way to do this includes three steps: (1) change D2 into a 6 hourly dataset (ND2) by linear interpolation; (2) simply keep the interpolated data ND2 during 1945–1948 and 1997–present; and (3) for the common period (1949–1996), make the tracks in D1 as long as possible by using information in D2, and correct suspicious data in D1 only when a typhoon track in D1 is outside of the region 15–50°N, 80–130°E and the distance between the two tracks is greater than 100 km. A typhoon is defined as an influencing typhoon when it produces a rainband over the mainland of China or any of the two biggest islands of China, Taiwan and Hainan. Thus, influencing typhoons include landfalling typhoons and those passing offshore around China. In this study, only these typhoon cases are dealt with. In addition, as a typhoon's duration generally lasts more than a week, it is important to define the time of occurrence. In this study, a typhoon's time of occurrence is defined as the date when it first produces a rainband over the mainland of China or over Taiwan or Hainan.

There are two daily precipitation datasets in this study. One dataset (D3) was obtained through bilaterial exchange between the China Meteorological Administration and the U.S. Department of Energy for the 196 China stations during 1951–1997. The other (D4) is the typhoon precipitation dataset from about 1400 stations during 1949–1996 from the Shanghai Typhoon Institute. A close inspection of the two datasets reveals that approximately all individual station data in D3 cover the whole period 1951–1997. However, in D4, all individual Taiwan station data and most individual northern China (north of the Yangtze River) station data just cover the period from the mid 1970s to the early 1990s, and most individual southern China (south of the Yangtze River) station data cover the period 1957–1996. Since it is southern China that is more easily influenced by typhoons, the period 1957–1996 was selected for this study and thus stations for which the data period does not cover 1957–1996 were not considered.

Defining typhoon precipitation is a very important step in this study. The practice of partitioning typhoon precipitation by analyzing synoptic 'hand–analysis' maps, which is applied in the Shanghai Typhoon Institute, may provide relatively accurate results, but it takes time and as people join the partitioning procedure, the results may not be objective. Therefore, it is necessary to apply an automatic and objective way to separate typhoon precipitation. One way to separate typhoon precipitation is by using a circle around the TC center. However, as it is revealed that there may be several discontinuous rainbands produced from a TC at a time, which are generally asymmetric around the TC center (Elsberry et al. 1987), a circle around the TC center cannot catch TC precipitation satisfactorily. In this study, a numerical technique for partitioning TC precipitation was developed and applied, and the results were compared to the synoptic ' hand–analysis' maps and were found to be in close agreement with them (Ren et al. 2001). This technique includes two steps. First, based on analyzing the structure of precipitation distribution, a daily precipitation field can be separated into different rainbands; then, for each raining station, the distance between it and the typhoon center and the distance between the weight center of the rainband which the station belongs to and the typhoon center are considered, then one can define the station precipitation as TC precipitation.

Gridded data are appropriate to inquire into the contribution to precipitation and the area of impact for a typhoon. In this study, a $0.5^{\circ} \times 0.5^{\circ}$ latitude–longitude grid is used. Inverse–distance interpolation was applied to transform the typhoon rainband station data into gridded data. To keep from expanding the typhoon rainband, the gridding procedure is limited to the region where the typhoon rainband is distributed. As a grid can also represent a quadrangle, it is easy to calculate the area represented by a given grid as

$$A_{grid} = (\pi r / 360)^2 \times \cos(\varphi) \ , \tag{1}$$

where r is the radius of the Earth, φ is the latitude of the grid, and A_{grid} is in km^2.

The values of A_{grid} were summed over the typhoon rainband grids to yield the size of the impacted area. The rainfall volume for a given grid can be calculated as

$$V_{grid} = A_{grid} \times P_{grid} \times 10^{-6} \ , \tag{2}$$

where P_{grid} is the grid precipitation in mm, V_{grid} is in km^3.

The values of grid rainfall volume V_{grid} were summed over the typhoon rainband grids to yield typhoon precipitation volume.

Additional insight into typhoon precipitation climatology was gained by analyzing the average annual station typhoon precipitation, its ratio to mean total precipitation, the minimum and maximum station annual typhoon precipitation, the minimum and maximum typhoon case station precipitation, annual impacted area, and annual typhoon precipitation volume over China.

Considering the different availabilities of D3 and D4, D3 was used during the whole procedure, while D4 was only used in partitioning typhoon precipitation and in gridding the data. However, during the investigation into contribution of annual typhoon precipitation to overall precipitation in China, only D3 was applied in gridding the data because only the 196 stations had continuous daily precipitation data during the period.

3. Results

Figure 1a depicts the frequency of influencing typhoons in China for each month. It clearly indicates that almost all (about 99.5%) of the 575 typhoons from the period 1957–1996 occur during May to November, with the most active season between July and September, especially during August in which 150 typhoons occur. Meanwhile, there are only two typhoons in April and one in January, which just passed offshore and affected parts of southeastern coastal regions of China, while no typhoon starting in February, March, or December influences China. Figure 1b displays that the influencing typhoon frequency shows prominent year–to–year fluctuations, varying from 6 in 1985 to 22 in 1978. It also shows that

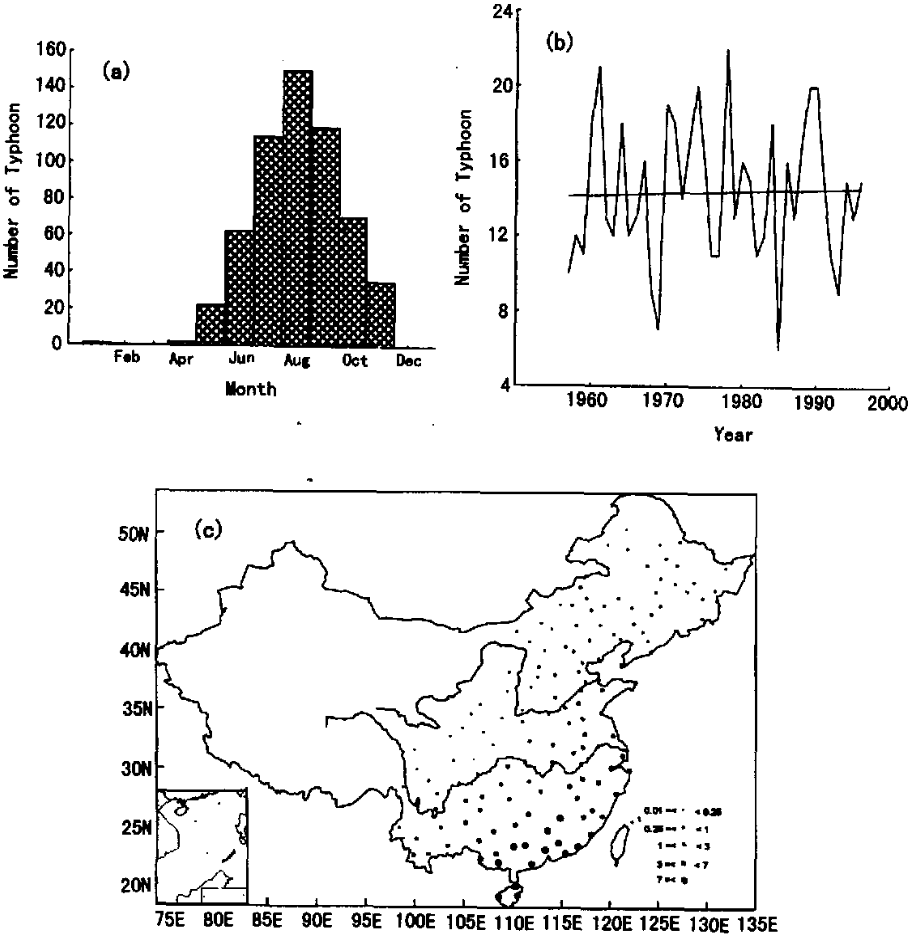

Fig. 1. Influencing typhoon frequency over China during 1957–1996. (a) Monthly distribution; (b) Annual time series; (c) Spatial distribution of average annual influencing typhoon frequency.

greater than normal numbers of typhoons affected China during the early 1960s, most of the 1970s, and 1989–1990, and fewer than normal numbers of typhoons appeared during the late 1950s, the late 1960s, 1985, and 1992–1993. However, it shows no significant time trend, with only a slight increase during 1957–1996.

The spatial distribution of average annual impacting typhoon frequency (Fig. 1c) shows that

(1) The typhoon influenced region is eastern China east of 98°E except western Inner Mongolia and most of northern Heilongjiang;

(2) Hainan, Guangdong, southeastern Guanxi, southern Fujian, and southern Jiangxi are the regions most frequently influenced by typhoons, with an average annual frequency of 7–9;

(3) Typhoon influence decreases as one moves northward and westward; that is, typhoon frequency is less than 1 in western China north of the Yangtze River and in northern China north of the Yellow River.

Figure 2 displays the climatology of typhoon precipitation in China during the period of study. Figure 2a presents the distribution of average annual typhoon precipitation. It shows

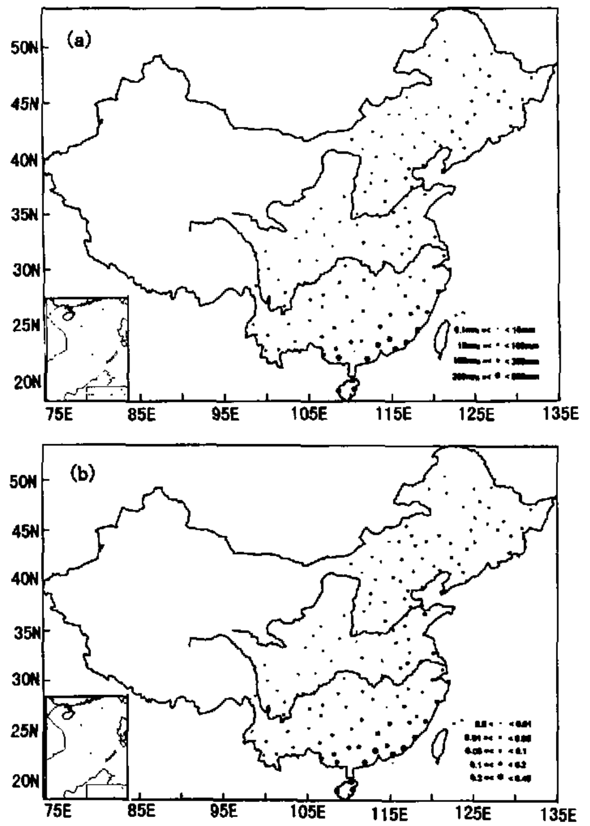

Fig. 2. Climatology of station typhoon precipitation during 1957–1996. (a) Spatial distribution of average annual typhoon precipitation; (b) Spatial distribution of ratio of average annual typhoon precipitation to average total rainfall; (c) Spatial distribution of minimum annual typhoon precipitation; (d) Spatial distribution of time trend of annual typhoon precipitation.

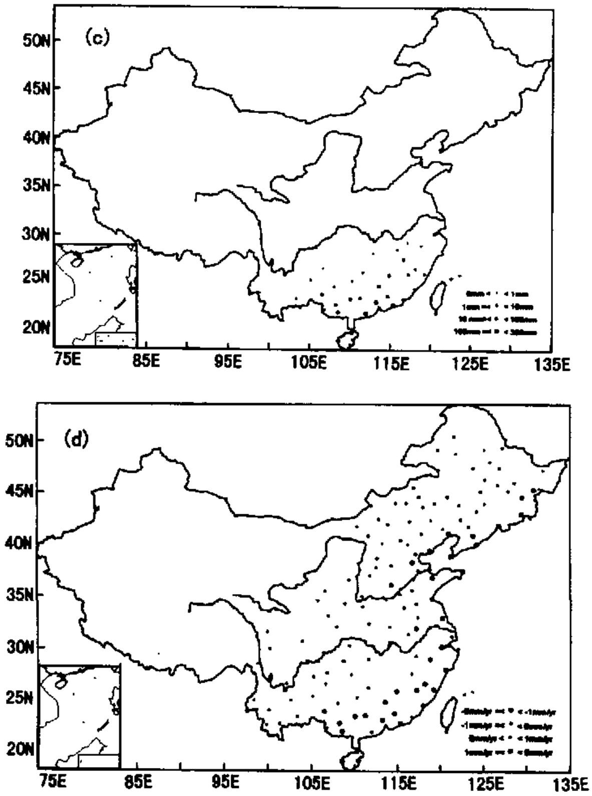

Fig. 2. (Continued).

that the largest amounts of average annual typhoon precipitation are observed in Hainan and the southeastern coastal regions, with values of 300–680 mm. Generally, only the coastal regions south of the Yangtze River receive precipitation of more than 100 mm, while most of the remainder of the typhoon–influenced regions receive 10–100 mm; Shanxi (west), parts of Inner Mongolia, and parts of Shanxi (east) receive less than 10 mm.

Figure 2b shows the distribution of ratio of average annual typhoon precipitation to average total rainfall. In eastern coastal regions, the ratio is between 5% and 10%, while the southeastern coastal regions mainly receive above 10%, with more than 20% in southern Guangdong and Hainan. Meanwhile, typhoon precipitation rates are less than 5% in the remainder of the typhoon–influenced regions. A comparison of Figs. 2a and 2b indicates that generally the larger average annual typhoon precipitation, the larger the ratio to total. The distribution of minimum annual typhoon precipitation (Fig.2c) shows that all regions that have been affected by typhoons during the period of study are south of the Yangtze River. Southern Guangdong and northern Hainan receive at least 100–150 mm rainfall, while Fujian, southern Jiangxi, Hunan, northern Guangdong, southern Hainan, Guangxi, and southern Guizhou receive somewhat smaller amounts of typhoon precipitation.

The annual time series of typhoon precipitation at each station were examined for time trends. Results displayed in Fig. 2d show that decreasing trends exist in most of the typhoon–influenced region, especially in the eastern and southeastern coastal regions with values of −5−1 mm yr^{-1}, while increasing trends exist in the coastal regions around the Beibu Gulf and most of central China. However, only trends in southern Northeast China are statistically significant at the 0.05 level by a Kendall test.

There were 575 typhoon cases that influenced China during 1957–1996. The scatter plot of precipitation volume (that reaches the ground) versus impacted area for each case and linear regression slope are presented in Fig. 3a. There exists a good relationship between the precipitation volume and the impacted area, which means that generally, the larger the typhoon impacted area, the larger the typhoon precipitation volume, with the correlation coefficient reaching 0.85. Their linear regression relationship is statistically significant at 0.01 level, even though, when the impacted area is small (less than 200 000 km^2), the precipitation volume just varies slightly, which is mainly accounted for by the observation that most of those areas are affected by the edge of outer typhoon. In addition, the maximum amount of

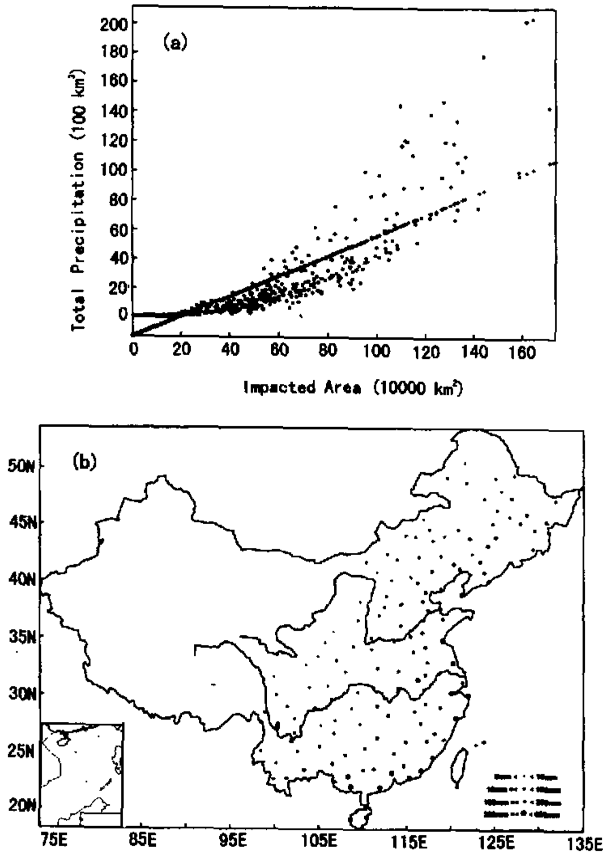

Fig. 3. Impacts of typhoon cases. (a) Scatter plot of precipitation volume versus impacted area and their linear regression line (" + "); (b) Spatial distribution of maximum single–case amounts of typhoon rainfall.

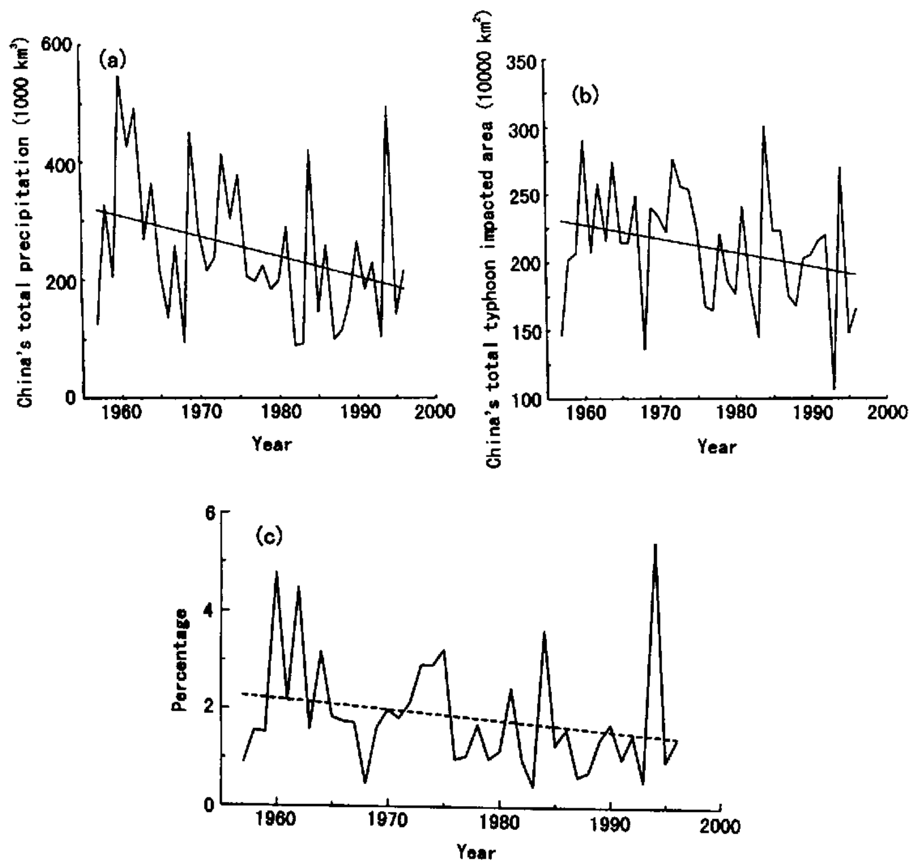

Fig. 4. Variations of typhoon impact on China's precipitation during 1957–1996. (a) Total annual volume of typhoon precipitation; (b) Total annual impacted area; (by comparison, China has a land area of 9 600 000 km^2) (c) Contribution of annual typhoon precipitation to overall precipitation.

typhoon rainfall received by stations during each case was examined, and Fig. 3b presents the distribution of maximum single–case amounts of typhoon rainfall. It is evident that in an extreme situation, a typhoon can produce more than 100 mm precipitation in southern Northeast China, eastern North China, the lower reaches of the Yellow River, the central and lower reaches of the Yangtze River, and all the coastal regions of China, with greater than 300 mm in eastern and southeastern coastal regions and a maximum of 613.2 mm in Hainan; the remainder receive less than 10–100 mm.

Figsures 4a and 4b present the variations of total annual volume of typhoon precipitation and total annual impacted area, which show prominent year–to–year fluctuations. There exists a good relationship between them, with the correlation coefficient being 0.77. During the early 1960s, most of the 1970s, 1984, and 1994, both plots show that China was seriously influenced by typhoons with large areas (more than 2.2 million km^2) of influence and large volumes of typhoon precipitation (above 30 000 km^3) reaching the ground. Meanwhile, during the late 1950s, the late 1960s, the early 1980s, and 1993, China experienced weak typhoon influence. Note that both plots exhibit a decreasing trend, but only the trend in total volume of typhoon precipitation is significant at the 0.05 level by a Kendall test. Figure 4c shows the annual time series of the contribution of annual typhoon precipitation to overall precipitation in the typhoon–influenced region (eastern China east of 98°E). It shows similar variations to those of Figs. 4a and 4b. The average contribution is 1.85%, with relatively large mean square error of 1.16%. There also exists a decreasing but insignificant trend during the period. According to an initial calculation in this study, the precipitation volume in the typhoon–influenced region occupies about 80%–90% of overall precipitation over all of China, so the contribution of typhoon precipitation to overall precipitation over all of China is similar to this result. Generally, a landfalling typhoon contributes more precipitation to China than a typhoon passing the offshore area around China. A comparison of Fig. 4a and Fig. 1b reveals that the number of typhoons and their intensity are very important factors in the extent of typhoon influence on China's precipitation. 1994 is one of the most seriously typhoon–influenced years and yet the frequency of influencing typhoons is just close to normal, since the number of landfalling typhoons is 11, which is 4 above normal, and their intensity is very strong.

4. Conclusions and discussions

The objectives of this study, as stated in the introduction, are accomplished. Available datasets and climatological studies are examined to show the frequency of influencing typhoons and their spatial distribution, the distribution of typhoon precipitation and its trend. Corresponding studies about typhoon cases and variations in typhoon contribution to precipitation are also examined.

From all of the results shown in this study, three main conclusions can be drawn.

(1) The main season during which typhoons affect China is from May to November, especially between July and September. The frequency of influencing typhoons shows no significant trend during the past 40 years.

(2) Hainan and the southeastern coastal–most regions are the most frequently affected by typhoons, and most of the regions south of the Yangtze River are affected by typhoons each year. In most of the typhoon–influenced regions, typhoon precipitation decreases during the period of study but this is only significant in southern Northeast China.

(3) There exists a significant linear relationship between precipitation volume and impacted area.

Particularly interesting is the significant decrease in total annual volume of typhoon precipitation in China during the past 40 years, which is consistent with the decrease in total annual impacted area. However, the decrease does not mean for a specific typhoon case that its precipitation volume and the ensuing damage were always less than any typhoon case before. For example, the famous typhoon case of "75.8", which occurred in August 1975, is more serious than most of the typhoon cases that occurred before it.

In fact, typhoon intensity is an important factor that affects typhoon influence. According to the inspection of time trends of typhoon case precipitation and impacted area, there exist relatively large, although insignificant, decreasing trends in both time series. Considering both the steady variations of annual frequency of influencing typhoons and the decreasing trend in typhoon case intensity, it is reasonable to conclude, at least tentatively, that this result reflects a real decrease in total annual volume of typhoon precipitation in China during the 40-year period.

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1957–1996 台风对中国降水的影响

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摘　要

台风活动是中国气候的重要特点之一，它能带来大量降水并造成严重的财产损失。在一些地区，台风降水甚至可以在总降水量中占很大比例。本文目的是研究那些对中国产生影响的台风并重点关注台风对中国降水的影响。文中涉及四个方面的工作。首先，研究了影响中国台风的频率，结果表明台风影响的主要季节为 5–11 月，尤其以 7–9 月频繁；在过去 40 年中影响台风的频率没有明显的变化趋势。第二，对台站台风降水的气候特征分析结果显示，海南和东南沿海地区受台风的影响最大，而且长江以南大部地区每年都受到台风的影响；另外，影响区域大部分地区的台风降水在过去 40 年中表现出下降的趋势，但是只有东北地区南部这种趋势是显著的。第三，对台风个例的分析表明，个例降水总量和影响面积之间存在着显著的线性关系。最后，对台风造成的中国范围降水总量进行了分析，初步结果显示台风降水总量在 1957–1996 年间显著减少。

关键词：热带气旋，影响中国台风，台风频率，台风降水