Thunder Events in China: 1980–2008

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Abstract Using data collected at 517 weather stations in contiguous China over the period 1980–2008, characteristics of thunder events have been investigated. These characteristics include geographical distribution, interdecadal variation, annual variation, and seasonal variation. The areas with the highest frequencies of thunder events are located in the central Tibetan Plateau, Yunnan, Guangxi, and Guangdong. The annual number of thunder days increases from northern to southern China. But the frequency of thunder events over mountains and plateaus is much higher than the frequency of events over plains in the same latitude. The interdecadal variation of events shows that the frequency of thunder occurrences was highest during the 1980s, decreased during the 1990s, and increased slightly afterwards. Thunder occurrences vary with the season, northward in May and retreating southward in September.

Keywords: thunder event, climatology, interdecadal variation, seasonal variation

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1 Introduction

A thunderstorm is also known as an electrical storm or a lightning storm. Many hazardous weather events are associated with thunderstorms and cause huge economic losses. Lightning strikes are responsible for many fires around the world each year that can cause death. Sometimes, rainfall associated with thunderstorms causes flash flooding. Large hail damages cars and windows, and hail kills wildlife in open spaces. Strong winds associated with thunderstorms knock down trees and power lines. Tornadoes can destroy all but the best built man-made buildings. Therefore, the study of thunder climatology and improvements in the prediction of thunderstorm are important steps in preventing and reducing the impacts of disasters.

Thunderstorm climatology has been well studied in Europe and North America. This research has focused on two major aspects of thunderstorms: the spatial and temporal characteristics. Prior studies of the climatology of thunder days (a 24-h period with one or more peals of thunder) have revealed considerable temporal variation in different areas of North America between 1901 and 1980 (Changnon Jr., 1985). Changery (1981) utilized station thunder data collected between 1948 and 1977 to determine annual and monthly frequencies of thunder events. Easterling and Robinson (1985) used the same data to examine certain aspects of the diurnal variation of thunder activities. Changnon Jr. (1988a, b) constructed both a temporal and spatial climatology of thunder events in the conterminous United States. The mean annual number of thunder days according to visual and aural observations made at weather stations were considered for the Finnish mainland during four periods: 1887–1936, 1931–50, 1970–86, and 1987–96 (Solantie and Tuomi, 2000). Thunder-day occurrences based on data taken from carefully screened records of 86 first-order stations distributed across the United States were assessed for temporal fluctuations and trends during the 100-year period of 1896–1995 (Changnon and Changnon, 2001). Using a 100-year (1896–1995) meteorological observation series in Cracow, Bielec (2001) analyzed the long-term variability of the number of days with thunderstorms. Annual and seasonal measures of thunderstorm-day occurrences in the contiguous United States for 1896–1995 were investigated using data from 841 weather stations (Changnon, 2003). In comparison to the large number of thunderstorm studies undertaken in Europe and the United States, little research on severe weather events has been conducted in China.

In China, some studies have investigated the climatology of severe weather. Zhang and Feng (1998) investigated the spatial and temporal distribution of the anomaly of annual average thunder days from 1960 to 1990. In that paper, the country was divided into four regions on the basis of the spatial distribution of thunder event frequency: the highest frequency in South China and southeastern China; the second highest frequency in Plateau and adjacent areas; the third highest frequency in North China, central China and the eastern part of Northwest China; and the lowest frequency in Northwest China. A study by Xu and Yang (2001) on the climatology of thunder events in South China revealed that thunder frequency decreased with latitude and that the areas of high frequency were typically mountainous areas. Ma et al. (2007) reanalyzed characteristics of thunder and lightning events in China, and this analysis indicated that thunderstorms moved north in the summer and retreated southwards in the winter. The spatial distribution of heavy rain, thunder, and hail events during 1968 to 2007 in China was statistically analyzed by Ren et al. (2008). However, the detailed thunderstorm climatology of the most recent 30-year period has not yet been analyzed.

The purpose of this paper is to give more detailed in-

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formation about both the spatial and temporal aspects of thunderstorm climatology from 1980 to 2008 (the year 2000 not included). Hail events are not included in our analysis because Ren et al. (2008) have already studied those events. Previous studies have focused only on some parts of China or have been limited to historical characteristics. In this study, the geographic distribution of thunderstorms over all of China in the most recent 30 year period (1980–2008) was the primary focus of our investigation. A further analysis of decadal and seasonal variations and the possible mechanisms driving them is also presented. Based on the variations of monsoon and rain bands during the summer season, the thunderstorm features for different regions were analyzed separately. The goal of this paper is to give a general description of the geographic distribution and variation in thunderstorms and the mechanisms driving that variation in the most recent three decades. This paper is organized as follows. Section 2 describes briefly the dataset used in the study. Section 3 discusses the geographic distribution of annual thunder days, interdecadal variation, annual variation, and seasonal variation. A summary and discussion of our findings are given in Section 4.

2 Data

The quality-controlled data used in this study was obtained from National Meteorological Information Center, China Meteorological Administration (NMIC, CMA). The dataset is compiled from the collection of global surface routine observations taken at 3-hour intervals from 1980 to 2008 (data for 2000 was not available). For historical and unexpected reasons, some stations were relocated and some were established during this period, as a result not all stations have a complete continuous record of data from 1980 to 2008. To ensure relatively high quality and continuous data records, we chose only stations with observations for more than 340 days each year, resulting in 517 stations in China with suitable data (Fig. 1a). Additionally, some representative stations were chosen to study the annual variation of thunder occurrence in different areas of eastern China (Fig. 1b), according to the

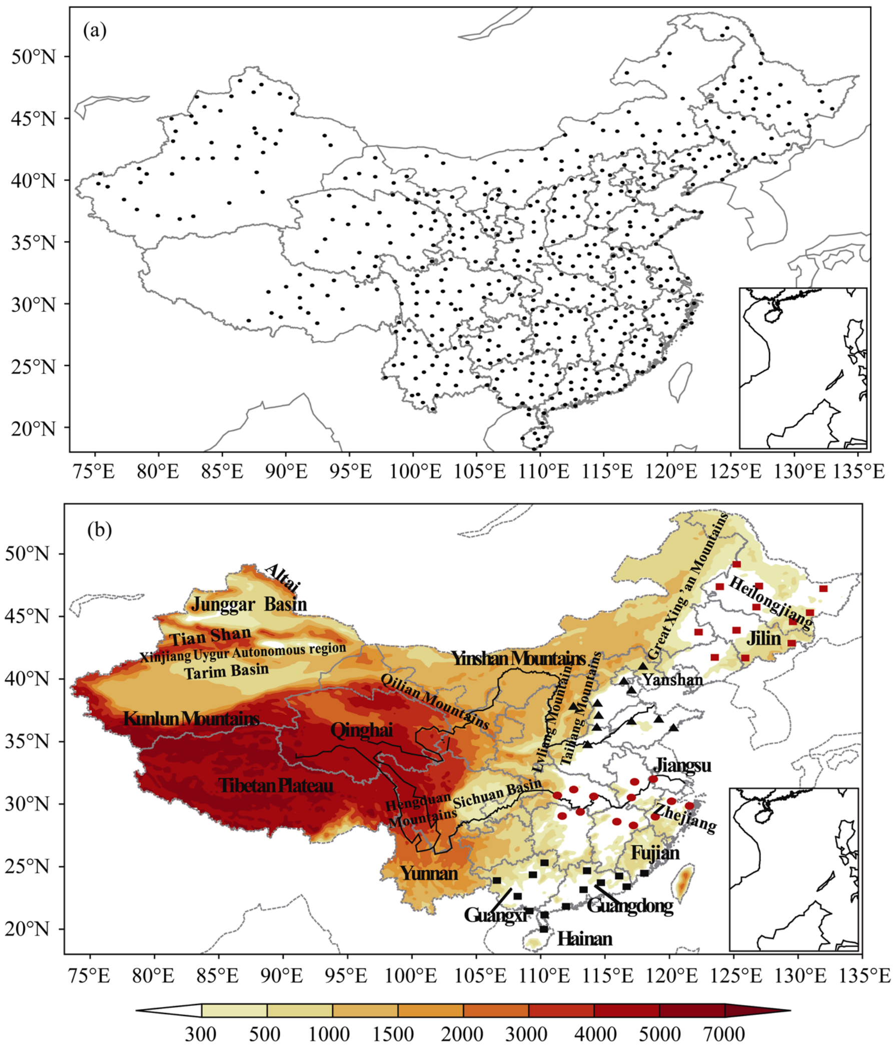

Figure 1 (a) Locations of the 517 stations in China with surface observation records of more than 340 days per year from 1980 to 2008 (the year 2000 not included). (b) The geographical distribution of mountains and rivers of China, with terrain shaded (Units: m). Also shown are the representative stations in South China (black square), the Yangtze River Basin (red dot), North China (black triangle), and Northeast China (red rectangle).

findings of a National Key Project for 1996–2000: "Studies on Short-Rang Climate Prediction System in China." Representative stations were prescribed in South China, the middle and lower reaches of the Yangtze River valley (YRV), North China, and Northeast China. However, some of these stations are not included in the 517 stations we selected, resulting in 14 stations in South China (Xiamen, Meixian, Shantou, Shaoguan, Heyuan, Guangzhou, Yangjiang, Zhanjiang, Haikou, Guilin, Liuzhou, Nanning, Beihai, and Baise), 13 stations along the middle and lower reaches of the YRV (Nanjing, Hefei, Hangzhou, Anqing, Wuhan, Zhongxiang, Yueyang, Yichang, Changde, Ningbo, Quzhou, Guixi, and Nanchang), and 11 stations in North China (Chengde, Beijing, Tianjin, Shijiazhuang, Xingtai, Anyang, Qingdao, Weifang, Jinan, Zhengzhou, and Taiyuan). The 12 representative stations (Nenjiang, Qiqihar, Hailun, Fujin, Jixi, Mudanjiang, Harbin, Changchun, Yanji, Tongliao, Tonghua, and Shenyang) in Northeast China are selected from 160 reference meteorological stations in China. The National Centers for Environmental Prediction (NCEP) final (FNL) 1°×1° from 2001 to 2008 was used to calculate Convection Available Potential Energy (CAPE), Convection Inhibition (CIN), and Lift Index (LI), which are parameters affecting the triggering and development of thunderstorms. The figures were not shown here because of the page limitation.

3 Results

3.1 Geographical distribution of annual thunder frequency

The annual thunder frequency from 1980–2008 in China is shown in Fig. 2a. The areas with the highest frequencies (thunder frequency greater than 60 days yr^{-1}) are located in the central Tibetan Plateau, the central south of Yunnan, the central south of Guangxi, and the central west of Guangdong. The regions with an annual thunder frequency greater than 60 days yr^{-1} are located below 25°N, with the exception of the Tibetan Plateau. The areas with an annual frequency greater than 30 days yr^{-1} include the northwest of Xinjiang Uygur Autonomous region, the mountainous areas in the northwestern part of North China, the central eastern part of the Tibetan Plateau, the western part of the Sichuan Plateau, and the southern part of the Yangtze River (except Sichuan Basin). The areas of high frequency in North China, West China, and the Tibetan Plateau are all plateaus or high mountain areas. These areas include the southern part of the Great Xing'an Mountains, the Yanshan Mountains, and the Taihang Mountains in North China; the Tianshan Mountains, the Qilian Mountains, and the Kunlun Mountains in Northwest China; and the Tibetan Plateau and the Hengduan Mountains in Southwest China. Obviously, thunder events in mountainous areas and over plateaus occur with greater frequency than that in plains or basins located at the same latitude. During the daytime, heating on the mountains and plateaus, combined with upslope winds, leads to a higher frequency of convection than occurs over the plains (Carbone et al., 2002; He and Zhang, 2010). The high thunder frequency observed in South China may be caused by warm water vapor, moist convective, available potential energy, and more unstable stratification (Tao et al., 1979). In addition, compared to the other regions of eastern China, a stronger instability and larger CAPE and CIN exist over South China throughout the entire year. These conditions are favorable to the triggering and development of convection events. Zhang and Feng (1998) discussed the geographical distribution of thunder events from the 1960s to the 1980s in China. They found that the annual frequency along the YRV was 40 days yr^{-1} and 90–110 days yr^{-1} in Guangdong, Guangxi, and Fujian provinces, with the highest frequency in central Guangdong. The annual thunder frequency during a 28-yr period from 1980 to 2008 is 20–30 days along the YRV, less than the value given by Zhang and Feng (1998). The difference between these two studies suggests that thunderstorms were less frequent from 1980 to 2008 than from 1960 to 1990. The climate changes which lead to this variation should be studied in the future. Nevertheless, the geographical distribution resulting from our analysis is generally consistent with Zhang and Feng's (1998), with the exception of the high frequency found in the northwest of Xinjiang, which may be caused by an increase in precipitation from the early 1980s to 2000 in Xinjiang (Huang et al., 2004; Wang and Cui, 2006).

3.2 Interdecadal variation of thunder occurrence

The interdecadal variation of thunderstorm frequency reflects the spatial distribution of thunderstorms in each decade. Due to limitations of the data, the thunderstorm frequency of the 2000s is represented by data from 2001 to 2008. The high frequency regions of South China, the Tibetan Plateau, North China, and Northeast China all show significant interdecadal variations (Figs. 2b–d).

In South China, the area with an annual thunder frequency of at least 50 days yr^{-1} was the largest during the 1980s and extended over a similar area during the 2000s. This area was the smallest during the 1990s. The area with a thunder frequency of at least 70 days yr^{-1} or more was largest during the 1980s and smallest during the 1990s. Compared to the 1990s, the area became a little larger during the 2000s, but extended eastward to the midwest of Guangdong.

In the Tibetan Plateau, the area with a mean annual frequency of 50 days yr^{-1} or more is located in the central Tibetan Plateau and extends eastward to the west of Sichuan and the Hengduan Mountains during the 1980s. The eastern area shrinks obviously while the western area expands southward during the 1990s. The area with a high frequency of thunder events shrinks and is split into western and eastern areas during the 2000s.

In North China and Northeast China, the area with an annual thunder frequency of at least 30 days yr^{-1} or more

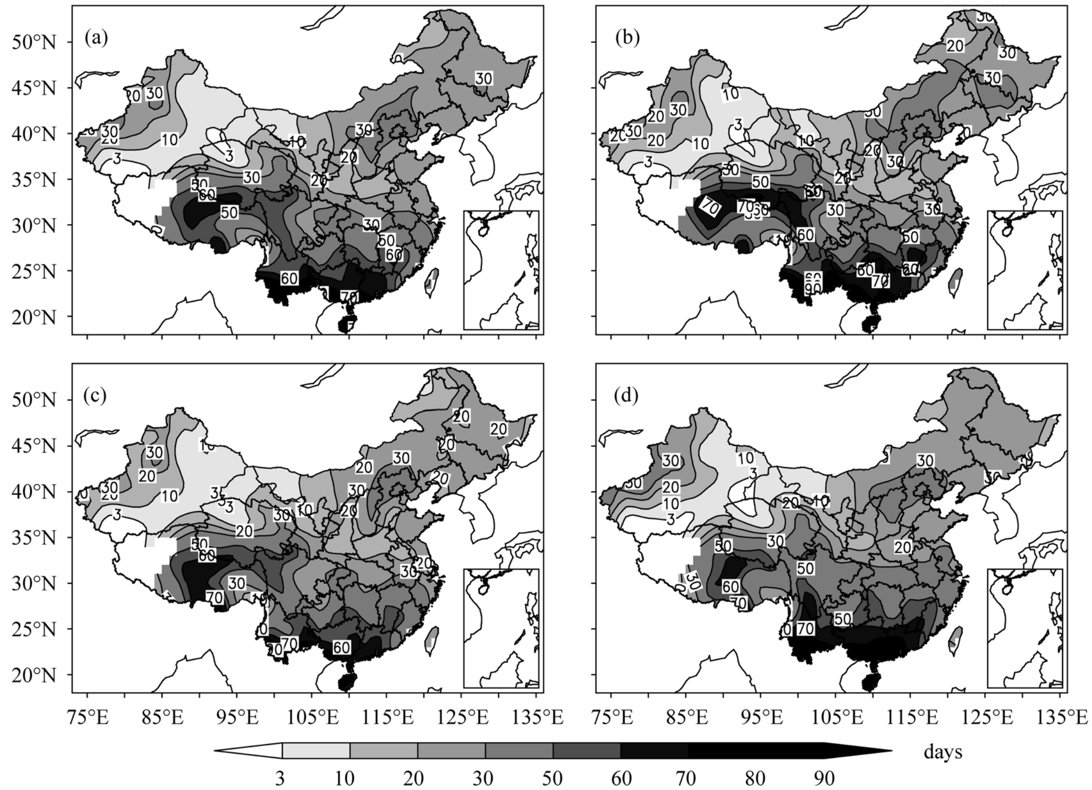

Figure 2 The geographical distribution of mean thunder frequency in China: (a) 1980–2008 (the year 2000 not included), (b)1980–89, (c)1990–99, and (d) 2001–08.

covers only a small area in northern Heilongjiang, central Jilin, and southwestern Heilongjiang provinces, extending from the central Great Xing'an Mountains to the Yinshan Mountains, the Lvliang Mountains, and the Taihang Mountains during the 1980s. During the 1990s, the annual thunder frequency in Northeast China declined to less than 20 days yr^{-1}, while the area with a thunder frequency of 30 days yr^{-1} in North China narrowed considerably to the Yanshan Mountains and the Taihang Mountains. The geographical distribution in the 2000s varied slightly from that of the 1990s, with the exception of a slight increase in North China.

To summarize, annual thunder frequencies were the highest in the 1980s, and decreased dramatically during the 1990s. Apart from a slight increase in frequency in South China, the geographical distribution of thunder events during the 2000s is consistent with that observed during the 1990s. According to Zhang and Feng (1998), a decreasing trend of thunder events also occurred in China during the 1980s. We find that a decreasing trend of thunder events has occurred during the most recent 30-year period.

3.3 Annual variation of thunder occurrence

With its large population and flourishing industries, thunder events in eastern China merit particular study. Eastern China spans a considerable range of latitudes; thus, the climate displays a range of various characteristics. According to the advance and retreat of the East Asian monsoon and precipitation band (Tao and Chen, 1987), the area can be divided into four regional types: South China, the middle and lower reaches of the YRV, North China, and Northeast China. The representative stations of these four regions are displayed in Fig.1b.

In South China (Fig. 3a), the annual thunder frequency is approximately 73 days yr^{-1}. It maintains a mainly positive anomaly from 1980 to 1987, with the exception of a slight negative anomaly in 1986. However, from 1988 to 2008, a negative anomaly is observed in most years, a finding consistent with earlier results indicating that thunder frequency decreased beginning in the late 1980s. The results show a significant decreasing trend in annual thunder days from 1980 to the early 1990s but a slow increasing trend afterwards.

In the middle and lower reaches of the YRV (Fig. 3b) the number of annual thunder days exhibits considerable variation from year to year, with a maximum of 46 days in 1987 and a minimum of 26 days in 1999. The decreasing and increasing variations alternate from 1980 to 1987, but generally show a positive anomaly. A negative anomaly is observed from 1988 to 2001, with the exceptions of 1991 and 1995. Positive anomalies are observed after 2001. Annual thunder frequency along the middle and lower reaches of the YRV shows a slow increasing trend in the early 1980s but a steady decreasing trend through the 1990s and no significant variation from 2002 to 2008.

In North China (Fig. 3c) the annual variation is quite distinct from both South China and the middle and lower reaches of the YRV. The number of annual thunder days varies greatly from 1980 to 1990, fluctuating around the average but showing an increasing trend. Positive anoma-

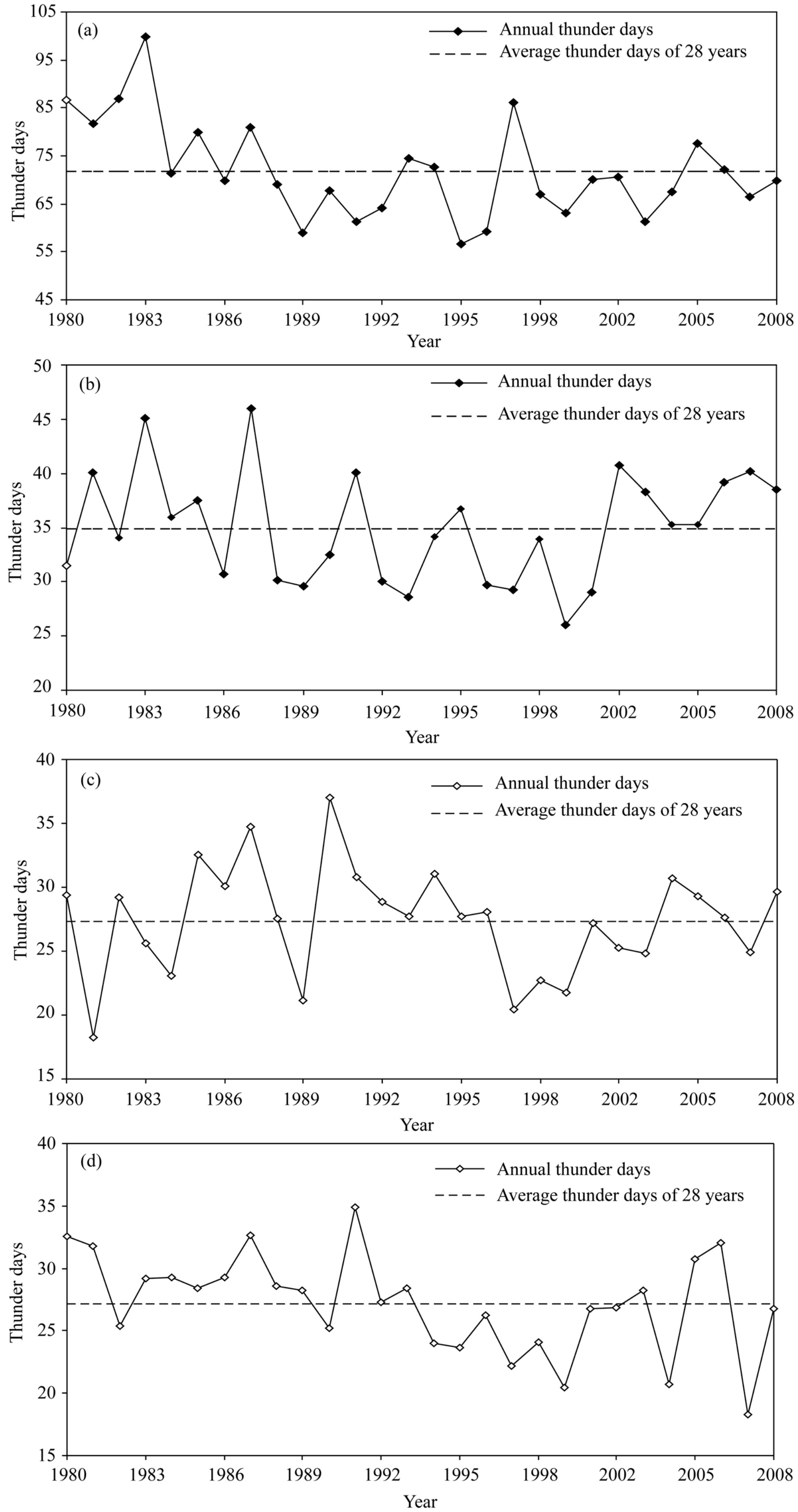

Figure 3 The annual thunder days during 1980–2008 (the year 2000 not included) at representative stations in different regions as shown in Fig. 1b: (a) South China, (b) the middle and lower reaches of the Yangtze River valley, (c) North China, and (d) Northeast China.

lies with no significant trend are observed from 1991 to 1996. The number of thunder days then decreases sharply in 1997 and shows an increasing trend thereafter. On the whole, an increasing trend is observed from 1980 to 1990, a decreasing trend is observed from 1991 to 1999 and an increasing trend is observed from 2000 on.

In Northeast China (Fig. 3d), there was no obvious variability in the number of annual thunder days from 1980 to 1990, and generally positive anomalies were observed with the exceptions of 1982 and 1990. The number of thunder days increased abruptly in 1991 and showed a decreasing trend from 1991 to 1999 with negative anomaly in most years. The number of thunder days was at an average level from 2001 to 2003, but varied markedly from 2004 to 2008. The long-term variation from 1980 to 2008 indicated that no evident change took place during the 1980s, and that a decreasing trend occurred during the 1990s but was followed by a slight increasing trend later.

To summarize, the annual variation in thunder frequency varies distinctly by region. This variation may be related to the annual variation of the rain belt in China. Although the rain belt in eastern China is mainly controlled by the East Asian monsoon, some other factors such as blocking highs, upper-level jets in the westerlies, and vortices in Northeast China can also affect convection activities and the rain belt (Tao, 1980).

3.4 Seasonal variation of thunder occurrence

The spatial distribution of thunder days is distinctive in different seasons (Fig. 4). The maximum number of total thunder days occurs in the summer while the minimum number occurs in the winter. In terms of the seasonal variation of spatial distribution, spring thunder events occur mainly in the south of China, extending from the Zhejiang and Jiangsu coast to central Tibet. Summer thunder events expand over a wider area, with summer thunder frequencies reaching five days per season in most areas, except for the Xinjiang-Qinghai border, the southwest of Xinjiang, and the Junggar Basin. Lower observed frequencies in these areas are attributed to the scarcity of observational stations and the arid or semi-arid climate. In the autumn, thunder frequency decreases sharply in the east of China, especially from the YRV to the Yellow River valley with an observed frequency of 1–3 days per season. In winter, the total thunder days are at a minimum, and the range over which thunder events occur is likewise the smallest, with a mean number of thunder days reaching one day or more found only in the south of the Yangtze River.

Figure 5 shows the monthly frequency of thunder days in the four regions of eastern China. In South China, the frequency of thunder events peaks from June to August with a maximum of 14 days in August. The number of thunder days can reach three or more days in most months, except for January, October, November, and December. There are two peaks of thunder frequency along the middle and lower reaches of the YRV. The first peak of thunder occurrence (up to four days) is in April, and the

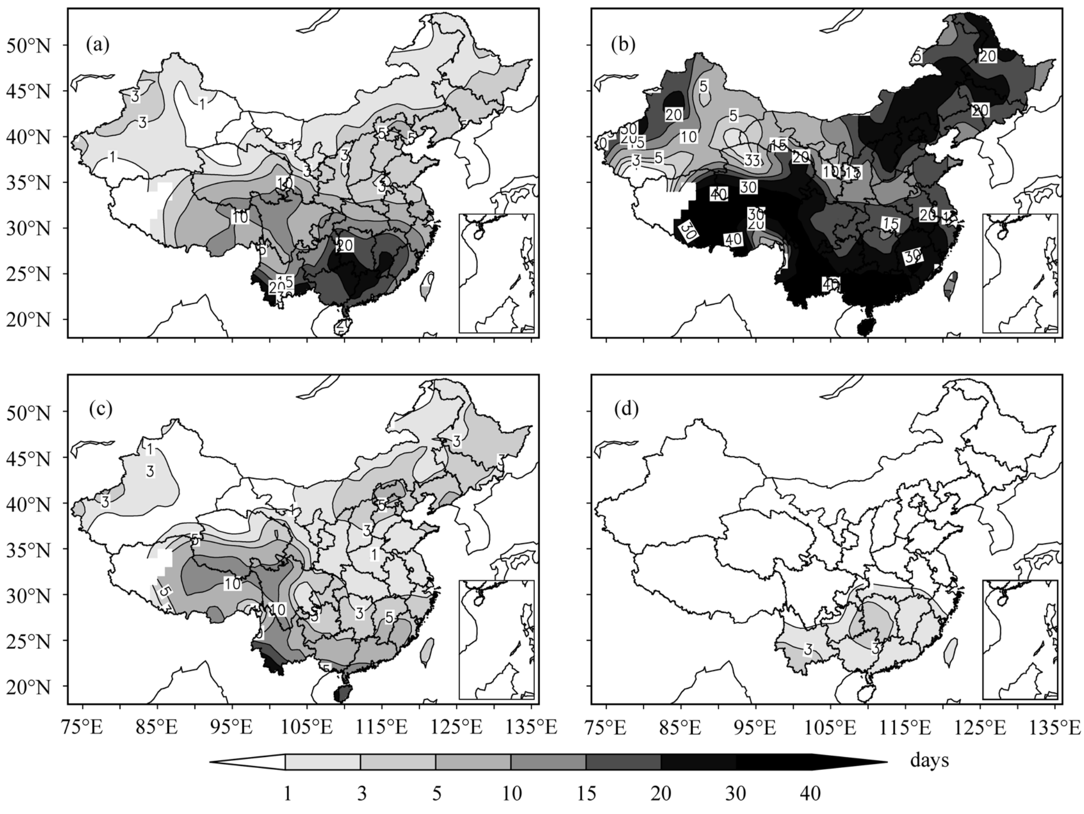

Figure 4 The geographical distribution of seasonal thunder frequency (thunder days per season) during 1980–2008 (the year 2000 not included): (a) March–May; (b) June–August; (c) September–November; and (d) December–February.

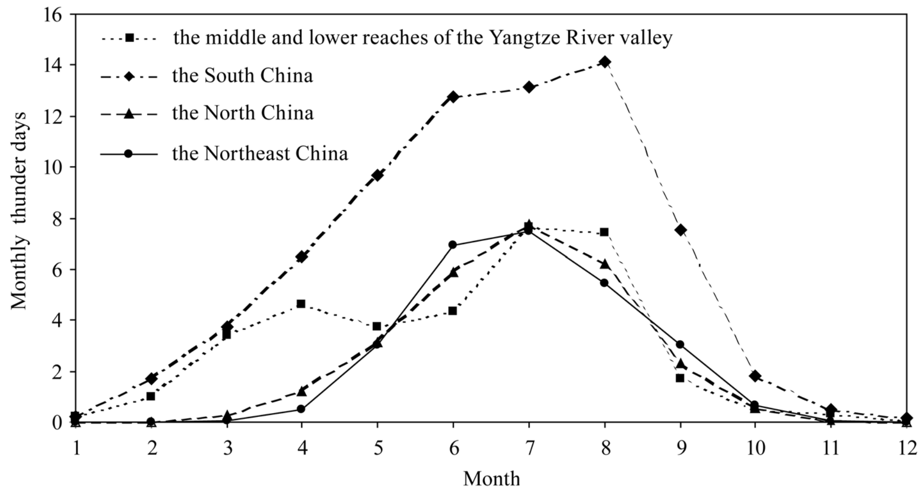

Figure 5 The annual monthly thunder days during 1980–2008 (the year 2000 not included) at representative stations in different regions as shown in Fig. 1b.

second peak (up to seven days) occurs in July and August. The first peak appears in the spring which is a period of high convection without a strong rain belt. In North China and Northeast China, the peak appears between June and August.

As for monthly variation, most thunder occurs in South China and along the middle and lower reaches of the YRV in March and April. In May and June, thunder events along the middle and lower reaches of the YRV decrease, but increase in North China and Northeast China. In July, a peak of thunder events appears in most regions with the exception of South China, where most thunderstorms occur in August. The area with a high thunder frequency starts to retreat southward in August, and retreats to South China in September, where monthly thunder frequency is highest. In South China, North China, and Northeast China, a peak of thunder events appears from June to August. There are two peaks, one in April and one in July–August along the middle and lower reaches of the YRV. The area with a high thunder frequency expands northward in May and retreats to the south in September.

As found in the analysis of seasonal variation, most thunder occurs in the south of China in the spring, the area of high thunder frequency then expands northward in the summer and shrinks back to the south in the autumn and winter. Seasonal variation of CAPE follows a similar pattern, with the high CAPE area occurring over southern China in the spring, expanding northward in the summer, and shrinking back to southern China in the autumn and winter. Additionally, the monthly variations of CAPE, CIN, and LI all have good correlation with thunder events in the four different regions. These variations and the seasonal movement of thunder events are caused by activities of the East Asian monsoon. As discussed by Zheng et al. (2008), the spatial distribution of mesoscale convective systems (MCS) in South China and East China is influenced by the East Asian summer monsoon, and the occurrence of thunder is closely related to MCS.

4 Summary and discussion

The climatology and characteristics of thunder events over China, such as the geographical distribution, interdecadal variation, annual variation, and seasonal variation, are investigated using global surface routine observations from 517 stations in China during the 1980–2008 period (the year 2000 is not included).

Areas with a high thunder frequency are located mainly in South China, the central south of Yunnan, the central east of the Tibetan Plateau, and the western Sichuan. The number of annual thunder days decreases with latitude, but the frequency of thunder events over mountains and plateaus is much greater than the frequency of events over plain areas at the same latitude. As the interdecadal variation of thunder occurrence demonstrates, maximum annual frequencies appear during the 1980s, and a minimum occurs during 1990s, with a slight increase following. The annual variation in eastern China shows distinct features in each of four subregions but presents an overall decreasing trend across all regions. Thunder occurrence appears to exhibit seasonal movement, expanding northward in May and retreating south in September. The seasonal movement of thunder may be related to activities of the East Asian monsoon, which can affect conditions governing the triggering and development of thunderstorms. Two peaks of thunder events along the middle and lower reaches of the YRV are revealed, with the first peak occurring in April and the second peak occurring between July and August.

As a result of this climatologic analysis of thunder frequency, the weather patterns and key factors controlling the occurrence of thunder events in eastern China will be investigated in a later study. The diurnal cycle of thunder storms over different regions and their formation mechanisms also will be studied in the future. Furthermore, key factors and formation mechanisms could be used for operational thunder storm predictions.

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