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Decadal variation of extreme drought and flood in North China revealed by documentary-based seasonal precipitation reconstruction for the past 300 years

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Abstract. Using the 17-sites seasonal precipitation reconstructions from an unique historical archive, Yu-Xue-Fen-Cun, the decadal variations of extreme droughts and floods (i.e., the event with occurrence probability of less than 10% from 1951 to 2000) in North China were investigated, by considering both the probabilities of droughts/floods occurrence in each site and spatial coverage (i.e., percentage of sites). Then, the possible linkages of extreme droughts and floods with ENSO (i.e., El Niño and La Niña) episodes and large volcanic eruptions were discussed. The results show that there were 29 extreme droughts and 28 extreme floods in North China from 1736 to 2000. Extreme droughts occurred more frequently (2 or more events) during the 1770s–1780s, 1870s, 1900s–1920s, 1940s and 1980s–1990s, among which the most frequent (3 events) occurred in the 1900s and the 1920s. While more frequent extreme floods occurred in the 1770s, 1790s, 1820s, 1880s, 1910s and 1950s–1960s, among which the most frequent (4 events) occurred in the 1790s and 1880s. For the total of extreme droughts and floods, they are more frequent in the 1770s, 1790s, 1870s–1880s, 1900s–1920s and 1960s, and the highest frequency (5 events) occurred in the 1790s. A higher probability of the extreme drought was found when El Niño occurred in the current year or the previous year. However, no significant connections were found not only between the occurrences of extreme floods and ENSO episodes, but also between the occurrences of extreme droughts/floods and large volcanic eruptions.

1 Introduction

Extreme climate events, such as drought, flood, can lead to high impacts on the natural environment and social system, such as water resources, agriculture, economic activity and human health and well-being. Based on the evidences from observed data since 1950, the IPCC (2012) special report concluded that several regions in the world, particularly southern Europe and West Africa, have experienced more intense and longer droughts; however, in central North America and northwestern Australia, droughts have become either less frequent, less intense, or shorter (with medium confidence). Meanwhile, there have been statistically significant increases in the number of heavy precipitation events (e.g., 95th percentile) in more regions than there have been statistically significant decreases over the world. Furthermore, the strong regional and subregional variations exist in both of extreme droughts and heavy precipitation events. For example, in China, it has been showed that the droughts appeared more frequently in Northeast China, North China and the eastern part of Northwest China during 1961–2013, with persistent, severe and widespread droughts from the late 1990s to early 2000s. Moreover, severe droughts also became more and more frequent in Southwest China in 2006–2013. Whereas, in the lower reaches of Yangtze River and the northern Xinjiang, the drought frequency tended to decrease from 1961 to 2013. Meanwhile, in North China, the southwest part of Northeast China and the western Sichuan Basin, a downward trend occurred in yearly rainstorm (i.e., ≥50mm/d) days. In most of central and East China, rainstorm days showed an increasing trend (Qin et al., 2015).

However, the instrumental measurements generally covered more than a half century, which cannot represent the full natural climate variability in many regions of the world as those derived from paleo-climate reconstructions, especially for the drought and flood (e.g., Cook et al., 2010; Ge et al., 2016; IPCC, 2012, 2013). Therefore, investigating variations in extreme climate events from long-term datasets is critical to identify whether the recent extreme events observed by instruments exceed the natural variability, which could provide more experience for adaptation to extremes and disasters in future (Qin et al., 2015), especially in regions with large precipitation variability and dense population, such as North China Plain (Wang et al, 2015).

Recently, there were several studies focused on the historical severe drought/flood events in North China, which is located in the sub-humid warm temperate zone with large precipitation variability dominated by the Asian monsoon. For example, based on "A Compendium of Chinese Meteorological Records of the Last 3000 Years" (Zhang, 2004), Zhang (2005) identified the 15 severe drought events that occurred in North China and surrounding area over the past 1000 years, and found that the most of historical drought events (i.e., those before 1950) were more severe than the extreme drought occurred in 1951-2000. Shen et al. (2008) investigated the characteristics of anomalous precipitation events during the past five centuries over eastern China (including North China and the mid-lower Yangtze River Valley), using the dataset of dryness/wetness grade over eastern China (CAMS, 1981), and found that in North China, the high frequency of severe and extreme floods occurred in the 1650s, 1660s, 1750s, 1760s, 1820s and 1890s, whereas the period of 1580–1650 and the 1990s witnessed more severe and extreme droughts. Meanwhile, the most three exceptional drought events over eastern China occurred in 1586–1589, 1638–1641 and 1965–1966, with 50% or more summer rainfall reduction. These events might be triggered by large volcanic eruptions and amplified by both volcanic eruptions and El Niño events (Shen et al., 2007). Our previous studies (Hao et al., 2010a; Zheng et al., 2006) identified the extreme drought/flood (single year or persistent) events for the past 2000 years by merging the annual dryness/wetness grade from individual sites. We found that there were more frequent extreme drought/flood events during the periods of 100–150, 550–650, 1050–1100, and 1850–1900 in North China Plain, while the frequency and intensity of extreme drought/flood events in the second half of the 20th century more closely resembled the mean status over the past 2000 years. Moreover, several other studies have focused on individual events reconstructions with large impacts on agriculture and society, such as the persistent extreme droughts in 1784–1786 (Zhang et al., 2000), 1876–1878 (Hao et al., 2010b; Man et al., 2000; Zhang et al., 2010) and 1927–1930 (Zeng et al., 2009); and the extreme floods in 1730 (Zhang and Liang, 2016), 1755 (Zhang et al., 2012) and 1917 (Ma et al., 2015). However, all these studies were performed from the yearly dryness/wetness grade data and relevant historical descriptions rather than quantitative precipitation reconstruction. Therefore, we present a case study, using seasonal precipitation reconstructions to investigate the decadal variations of extreme drought and flood in North China for the past 300 years, which is helpful to understanding of the contributions to the agriculture, social activity from the extreme climate occurred at seasonal scale.

2 Data and method

2.1 Data

Three datasets were used in this study, including seasonal precipitation reconstruction, chronology of El Niño and La Niña events, and chronology of large volcanic eruption.

(1) Seasonal precipitation reconstruction. This dataset was reconstructed from a unique historical archives of Yu-Xue-Fen-Cun, i.e., the quantitative records of the depth of infiltration into soil after each rainfall or the depth of each snowfall on the surface (Ge et al., 2005), together with available instrumental data. It included spring, summer, autumn and winter precipitation at 17 sites (Fig. 1) located in North China (34°N–39°N, east of 108°N approximately) during 1736–2000 with annual resolution (Zheng et al., 2005). While 8 (i.e., Xi'an, Taiyuan, Shijiazhuang, Cangzhou, Ji'nan, Anyang, Weifang, and Linyi) of 17 sites had complete records for the entire period (1736–2000), the other 9 sites involve some missing records in 1911–1950. The calibration method for the rainfall reconstruction from historical infiltration depth records was derived from the Green-Ampt infiltration model and surface water balance equation. The field infiltration experiment for reconstruction model validation showed that the predicted R^2 (i.e., explained variance of reconstructed series) for the rainfall reconstruction reached to 87%. The snowfall reconstruction was calibrated by the regression equations based on the data of instrumental precipitation and snowfall depth from each weather station, which resulted in the predicted R^2 of 62-82% for different sites (Zheng et al., 2005). Such high predicted R^2 value enabled these reconstructions to adequately capture a majority of the precipitation variability and extreme events.

(2) Chronology of El Niño and La Niña events. This chronology was reconstructed from tree-ring, ice-core, coral records and historical documents by Gergis and Fowler (2009). There were 119 El Niño and 127 La Niña events identified during 1736-2000. The magnitude of these El Niño/La Niña events was categorized into five grades with extreme (E), very strong (VS), strong (S), moderate (M), and weak (W).

(3) Chronology of large volcanic eruption. The chronology of large volcanic eruption used in this study was extracted from the database of "Volcanoes of the World" released by the Smithsonian Institution (Global Volcanism Program, 2013). This dataset includes information on volcano location (longitude, latitude and elevation), starting and ending dates of eruptive activity, tephra volume, and volcanic explosivity index (VEI) for each eruption, in which the VEI is determined by the eruption type and duration, the tephra volume, and the height of the eruption cloud column. Only the eruption with VEI ≥ 4 was extracted as large eruptions for this study, and there were 137 large eruptions occurred in 1736–2000.

2.2 Method

Firstly, we calculate the threshold for probability of 10%, 20%, 80% and 90% occurrence based on the 17-site precipitation reconstruction series according to Gamma distribution, to identify the year when the severe or extreme drought/flood occurred. For each site, the severe drought (or flood) means that the annual precipitation was lower (or upper) than the threshold for probability of 20% (or 80%), and the extreme drought (or flood) was defined as being lower (or upper) than the threshold for probability of 10% (or 90%). Then, we calculate the percentage of sites with extreme and severe drought (or flood) occurred (Fig. 2) over North China. It's shown that the top five (i.e., 10% occurrence) drought events between 1951-2000 (i.e., instrumental period) occurred in 1997, 1986, 1965, 1981 and 1991; and the top five flood years were 1964, 1958, 1963, 1956 and 1961. Therefore, we use the minimum percentage of severe and extreme drought (flood) sites among these years, i.e., 35% (35%) and 29% (24%) for severe and extreme drought (flood) respectively, as the criteria to identify the regional extreme drought/flood events in 1736–2000 over North China. Finally, we compared the extreme drought/flood events with the El Niño/La Niña chronology and the large volcanic eruption chronology, to illustrate the characteristics on connections between extreme drought/flood events, and El Niño/La Niña episodes, and large volcanic eruptions, respectively.

3 Results and discussion

3.1 Occurrence of extreme drought and flood

There were 29 extreme drought events and 28 extreme flood events identified (Fig. 2) in 1736–2000. Extreme drought events occurred in 1743, 1777, 1778, 1783, 1786, 1792, 1805, 1813, 1847, 1856, 1869, 1876, 1877, 1900, 1901, 1902, 1916, 1919, 1920, 1922, 1927, 1936, 1939, 1941, 1965, 1981, 1986, 1991 and 1997. Extreme flood events occurred in 1742, 1751, 1774, 1776, 1794, 1797, 1798, 1799, 1800, 1822, 1823, 1830, 1858, 1867, 1872, 1882, 1883, 1886, 1889, 1890, 1910, 1914, 1937, 1956, 1958, 1961, 1963 and 1964. Figure 3 illustrates the box-whisker plot of seasonal precipitation anomaly percentage among 17 sites for each extreme drought and flood event. It's shown that for a majority of extreme drought (flood) events, precipitation decreased (increased) evidently at most of sites for four seasons, especially for summer and autumn, because the precipitation in summer and autumn accounts for approximately 60% and 20% of the annual precipitation, respectively. For example, at the extreme drought year of 1877, the regional precipitation anomaly (i.e., referenced to the average of all sites over entire study area relative to the mean precipitation of all years) was -25% in spring, -53% in summer, -53% in autumn, and -23% in winter. In the extreme flood year of 1890, the regional precipitation anomaly was 37% in spring, 32% in summer, 23% in autumn, and 30% in winter. Whereas, in drought years of 1902 and 1981, precipitation only decreased in summer slightly, but it decreased evidently in other three seasons. Similarly, the precipitation anomalies for different seasons at different sites also existed in several extreme flood years, such as 1794, 1823, 1867, 1872 and 1961.

Compared to the extreme droughts and floods reported in previous studies (Chen et al., 2013; Hao et al., 2010a, b; Shen et al., 2007, 2008; Zhang et al., 2005; Zheng et al., 2006), besides of extreme drought years and extreme flood years (i.e., 1751,

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1800, 1822, 1823, 1883, 1889, 1937, 1956, 1963 and 1964) identified in their publications, 9 extreme drought events and 18 extreme flood events (marked "↑" in Fig. 2) were revealed which were not reported before. Moreover, our results also eliminated those events that the intensity may have been overestimated by the previous studies, which resulted from droughts/floods only at sub-regional scale or for a short duration. For example, 1785 and 1825 were reported as extreme drought years by Chen et al. (2013) and Hao et al. (2010a), respectively. However, the drought in 1785 occurred only from late spring to early summer at several sites in the southern part of North China, and it did not prevail over the entire study area. The drought of 1825 occurred in summer over approximately half of North China, but in spring, rainfall increased by more than 50% across nearly the entire region. Such similar situations also occurred in 1826, 1832, 1846, 1878, 1899, 1928, 1929 and 1972. Meanwhile, 1757, 1761, 1819, 1894, 1898 and 1973 were reported as extreme flood years by Shen et al. (2008) and Hao et al. (2010a). However, in 1757, the notable precipitation increased only in the southern of North China, except that more snowfall occurred at most sites of the entire study area in winter. . In 1761, floods occurred over almost half of the region in spring only. However, only 2 sites occurred severe drought and 3 sites experienced extreme flood throughout the whole year. In 1819 and 1894, except more snowfall occurred for most sites in winter, there were only a few sites experienced severe flood, but no sites occurred extreme flood throughout the year. In 1898, more precipitation only occurred in spring but not for other seasons. In 1973, only 6 of 17 sites experienced severe floods but no extreme floods occurred at any sites throughout the year, despite 1 site of them occurred extreme rainfall during summer time. Thus, these years cannot be identified as the extreme flood events in our result.

3.2 Decadal variation of extreme droughts and floods

Figure 4 illustrated the frequency of extreme drought and flood in North China for each decade from 1740s to 1990s. It showed that the extreme drought occurred more frequently in the 1770s–1780s, 1870s, 1900s–1920s, 1940s and 1980s–1990s with at least 2 extreme events for each decade, and the two decades of the 1900s and the 1920s both occurred 3 events. Moreover, some of them occurred within 2–3 years on a roll, e.g. in 1777–1778, 1876–1877, 1900–1902, 1919–1920. These consecutive events usually caused severe impacts on agriculture and society. For example, the droughts in 1876–1877 led to evidently poor crops harvests with decreasing of about 45% and 50% in 1876 and 1877 respectively (Hao et al., 2010b). Even worse, this consecutive extreme drought further caused evidently delayed sowing and crop failure within several years after 1877, and led to the rice price increased by 5–10 times than that in the normal year (Hao et al, 2010b). Such persistent and large spatial poor harvests and food scarcities not only caused more than one hundred million people in famine, but also triggered more than one hundred thousand refugees emigrated from North China Plain to eastern Inner Mongolia (Xiao et al., 2011b); which finally resulted in more than 13 million people died from famine and plague (Li et al., 1994). Whereas, there were no extreme droughts in the 1750s–1760s, 1820s–1830s, 1880s–1890s, 1950s and 1970s.

More frequent extreme floods occurred in the 1770s, 1790s, 1820s, 1880s, 1910s and 1950s–1960s with two or more occurrences per decade, but no extreme flood occurred in the 1760s, 1780s, 1810s, 1840s, 1900s, 1920s, 1940s and 1970s–1990s. Meanwhile, the most frequent extreme floods (4 events) occurred in the 1790s and the 1880s respectively, in which the consecutive extreme χ^2 flood years in 1797-1800 caused flowages from several rivers and resulted that approximately 1/4 of the total counties in North China Plain were flooded (Zheng et al., 2016). Moreover, 4 extreme flood years in the 1880s caused the continuous breaching of the dyke along the Yellow River from 1882 to 1890 (Zhang, 2010).

For the extreme drought and flood events in total, more frequent of them occurred in the 1770s and 1790s, 1870s–1880s, 1900s–1920s and 1960s, among which the 1790s witnessed the highest frequency of extreme drought and flood events totally. Such frequently extreme droughts and floods, together with climate cooling from the late of 18th century, resulted that the regional socioeconomic system became more vulnerable around the turn of the 19th century in North China Plain (Fang et al, 2013). This is because that more frequent extreme floods/droughts caused many negative impacts, e.g., vulnerable food security, significant increase of disaster victims, which further led to the deterioration of refugee relief and more occurrence of peasant uprising (Xiao et al., 2011a). However, no extreme drought or flood event occurred in the 1760s and the 1970s.

3.3 Probabilities of the occurrences of extreme events with ENSO events and large volcanic eruptions

Table 1 shows the occurrences of ENSO (i.e., El Niño and La Niña events) and large volcanic eruptions (i.e., VEI $\geq$ 4) in the extreme drought/flood years and their previous years. It's shown that among the years before 29 extreme droughts, 19 of them were El Niño years, 8 of them were La Niña years, 2 of them did not experience ENSO event; and 10 of them experienced large volcanic eruptions. Among the 29 extreme drought years, 17 occurred in El Niño years, 8 occurred in La Niña years, 4 years did not experience ENSO events; and 12 years experienced large volcanic eruptions (Table 2). While among the years before 28 extreme flood events, 11 of them were El Niño years, 9 of them were La Niña years, 8 of them did not experience ENSO events; and 11 of them experienced large volcanic eruptions. Among the 28 extreme flood years, there were 8 El Niño years, 13 La Niña years, 7 years did not experience ENSO events; and 12 years experienced large volcanic eruptions (Table 2). In total, 17 of the 29 extreme drought events and 18 of the 28 extreme flood events coincided with the occurrence of large volcanic eruptions in either the same or the previous year (Table 2).

The Chi-square test (χ^2) showed that there is a higher probability of the extreme drought with the El Nino occurrence in the same year or the previous year. For example, the chi-square value is 7.997 for the occurrence of extreme drought and El Nino in the previous year, which is significant at the $p<0.01$ level. Regarding the occurrence of extreme drought and El Nino in the same year, the chi-square value is 4.502, which passes the $p<0.05$ significant level. Hao et al (2008; 2010b) found that the precipitation over the North China Plain was below normal years in the occurrence of the El Nino year or the next year, and the severe drought of 1876-1877 was associated with the strong El Niño episode. Chen et al (2013) and Li et al (2011) also found that most of drought events or extreme dry years in North China may have a close link with the occurrence of El Nino during historical times. Our result confirmed their findings again. However, we also found that there is no significant connection for the occurrences between extreme flood and ENSO events. In addition,, the chi-square test suggested that no significant link exists between the occurrences of extreme drought/flood events and large volcanic eruptions, although Shen et al (2007) had argued that the large volcanic eruptions might trigger the exceptional drought events over eastern China.

4 Conclusions

This study investigated the decadal variation of extreme drought/flood over North China based on the 17-sites seasonal precipitation reconstructions in 1736-2000, in which the extreme drought/flood events were defined as those with occurrence probability lower than 10% in reference period of 1951-2000, by considering the probability of drought/flood occurrence in each site and spatial coverage together. It's found that there were 29 extreme droughts and 28 extreme floods in North China during 1736-2000, in which precipitation decreased (increased) evidently in most sites for all seasons, especially in summer and autumn for most of them. While in 1777–1778, 1876–1877, 1900–1902 and 1919–1920, the extreme droughts occurred sequentially, and in 1797–1800, 1882–1883, 1889–1890 and 1963–1964, the extreme floods appeared in a roll. Compared to the previous studies on extreme droughts and floods derived from the yearly dryness/wetness grade data, this study find 9 extreme drought events and 18 extreme flood events that had not been reported previously.

Moreover, the results showed that there was an evidently decadal variation in the occurrence of extreme drought/flood events from 1740s to 1990s. In the 1770s–1780s, 1870s, 1900s–1920s, 1940s and 1980s–1990s, the extreme drought occurred at least 2 times in each decade, among which the most frequent occurrences (3 times) were in the 1900s and the 1920s. While twice or more extreme floods occurred in the 1770s, 1790s, 1820s, 1880s, 1910s and 1950s–1960s, with 1790s and 1880s having the most frequent occurrences (4 times). As the extreme drought and flood events in total, there were more frequent in the 1770s, 1790s, 1870s–1880s, 1900s–1920s and the 1960s, and the most frequent (5 events) decade were in the 1790s. In addition, the comparison and of the occurrences of extreme drought/flood with the chronologies of ENSO and large volcanic eruption by the Chi-square test (χ^2) confirmed that there was a higher probability of the extreme drought followed the El Nino episode. Whereas, no significant connection existed either between the occurrences of extreme flood and El Niño/La Niña episodes or between the occurrences of extreme drought/flood and large volcanic eruption.

Competing interests. The authors declare that they have no conflict of interest.

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Figures

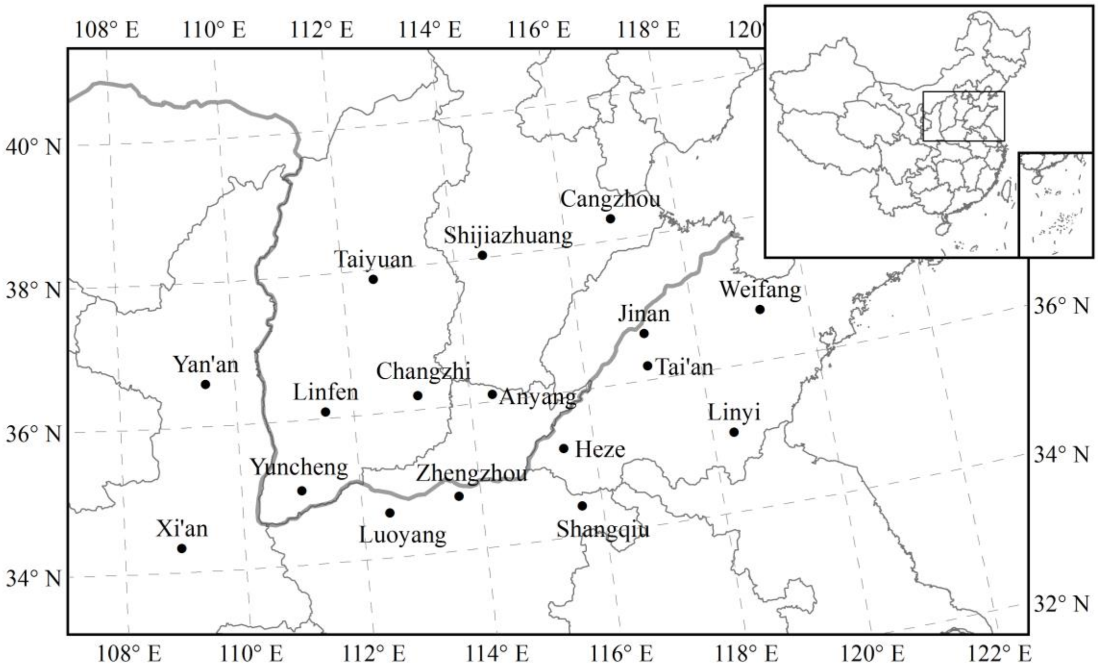

Figure 1. The location of 17 sites with seasonal precipitation reconstruction for 1736-2000.

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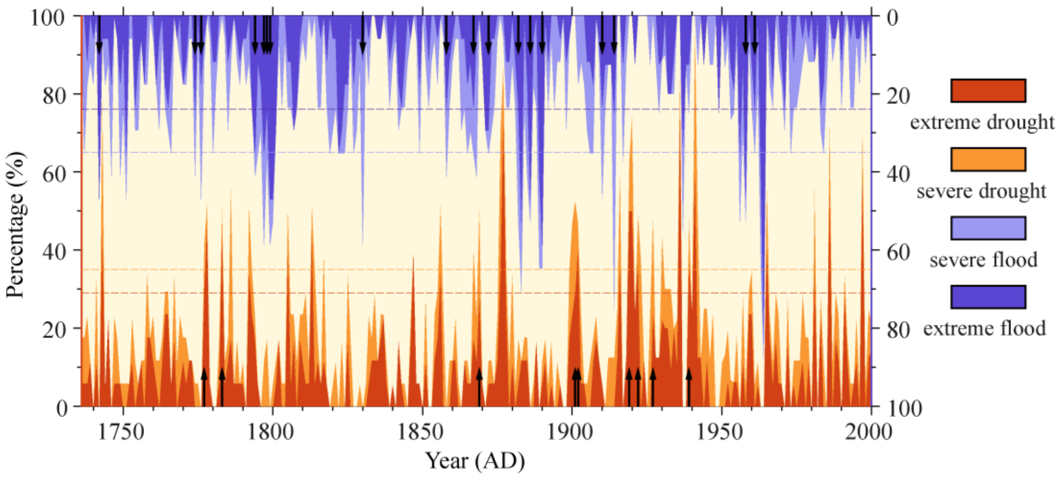

Figure 2. Percentage of sites with extreme and severe drought/flood occurred over North China in 1736–2000. Dash line: the criteria to identify the regional extreme drought/flood events respectively. ↑: The year of extreme drought/flood events which were not reported in previous studies (Chen et al., 2013; Hao et al., 2010a, b; Shen et al., 2007, 2008; Zhang et al., 2005; Zheng et al., 2006).

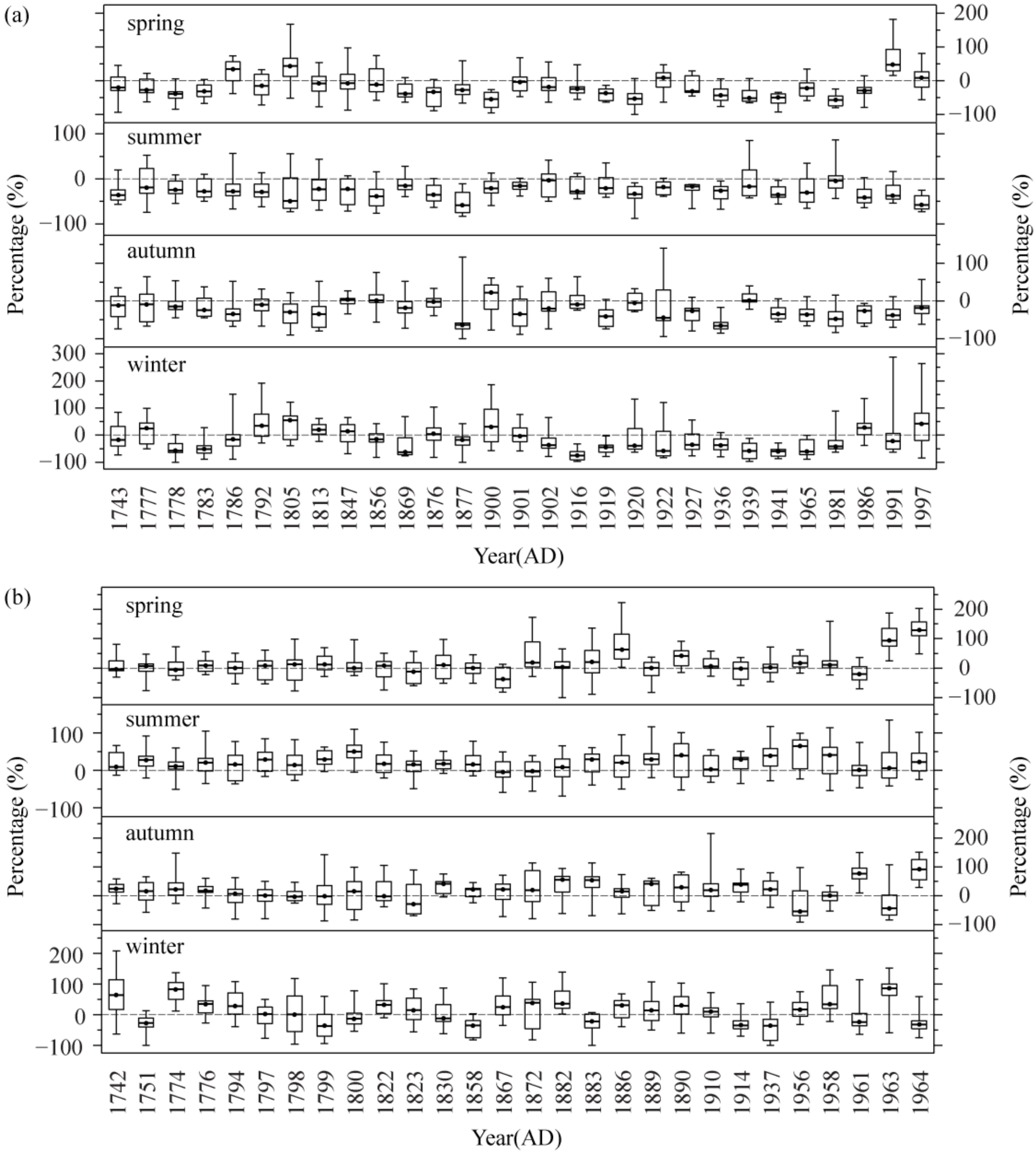

Figure 3. The box-whisker plot of seasonal precipitation anomaly percentage among sites for each extreme drought (a) and flood (b) event.

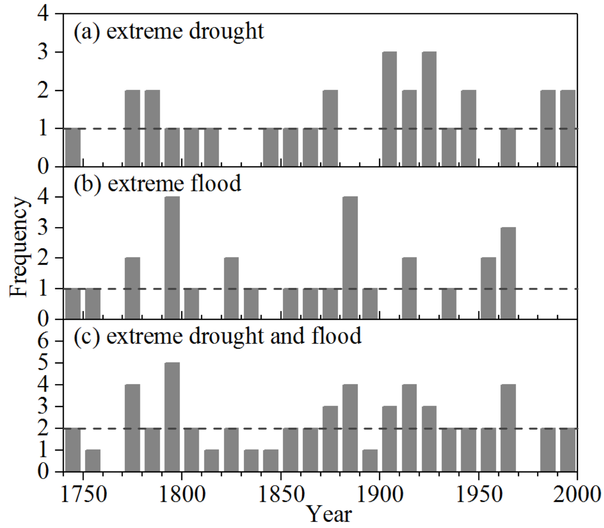

Figure 4. The frequency of extreme drought and flood in North China for each decades from 1740s to 1990s.

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Tables

Table 1. The occurrences of El Niño and La Niña event and large volcanic eruption in the extreme drought/flood year and its previous year

Extreme drought year	El Niño/La Niña occurred	Large volcanic eruptions (year/month)	Extreme flood year	El Niño/La Niña occurred	Large volcanic eruptions (year/month)
1743	L_{E}/1742→L_{VS}/1743	-	1742	L_{S}/1741→L_{E}/1742	1741/8
1777	L_{W}/1776→E_{W}/1777	-	1751	L_{S}/1750→L_{M}/1751	1750/?
1778	E_{W}/1777→L_{W}/1778	1778/?	1774	L_{W}/1773	-
1783	E_{W}/1782→E_{M}/1783	1783/6, 1783/8	1776	L_{W}/1776	-
1786	L_{W}/1785→L_{S}/1786	1786/?	1794	E_{M}/1793→E_{M}/1794	1793/2, 1793/3
1792	E_{VS}/1791→E_{W}/1792	-	1797	L_{M}/1797	-
1805	E_{W}/1804→L_{VS}/1805	-	1798	L_{M}/1797→L_{W} /1798	-
1813	E_{S}/1812→L_{M}/1813	1812/4, 1812/8, 1813/?	1799	E_{W}/1798→E_{S}/1799	-
1847	E_{W}/1846→L_{S}/1847	1846/6	1800	E_{S}/1799	1800/1, 1800/?
1856	E_{M}/1856	1856/9	1822	-	1822/3, 1822/10
1869	E_{VS}/1868	-	1823	L_{M}/1823	1822/3, 1822/10
1876	L_{S}/1875→E_{W}/1876	1875/3	1830	E_{W}/1829	1829/9
1877	E_{W}/1876→E_{VS}/1877	1877/6, 1877/?	1858	L_{W} /1857→E_{M}/1858	1857/1
1900	E_{S}/1899→E_{VS}/1900	1899/11	1867	L_{M}/1866→L_{S}/1867	-
1901	E_{VS}/1900→E_{S}/1901	-	1872	L_{VS}/1871→L_{M}/1872	1872/4, 1872/?
1902	E_{S}/1901→E_{VS}/1902	1901/5, 1901/5, 1901/5, 1901/10	1882	E_{M}/1881	-
1916	E_{VS}/1915→L_{S}/1916	-	1883	-	1883/8,1883/10
1919	E_{VS}/1918→E_{S}/1919	1918/4, 1918/10, 1919/5, 1919/8	1886	E_{S}/1885→L_{M}/1886	1886/1, 1886/6, 1886/8
1920	E_{S}/1919→E_{W}/1920	1919/5, 1919/8	1889	E_{VS}/1888→E_{W}/1889	1888/7, 1889/10
1922	L_{W}/1921→L_{S}/1922	-	1890	E_{W}/1889→L_{S}/1890	1889/10, 1890/2
1927	E_{E}/1926	1926/4	1910	L_{VS}/1909→L_{VS}/1910	-
1936	E_{W}/1935	-	1914	E_{VS}/1913→E_{VS}/1914	1913/1, 1914/1
1939	E_{M}/1938→E_{M}/1939	-	1937	E_{W}/1937	1937/5
1941	E_{VS}/1940→E_{E}/1941	-	1956	L_{S}/1955→L_{M}/1956	1955/7, 1956/3
1965	L_{W}/1964→E_{S}/1965	1964/11, 1965/9	1958	E_{S}/1957→E_{S}/1958	-
1981	E_{W}/1980	1980/5, 1981/4, 1981/5	1961	-	-
1986	L_{M}/1985→E_{M}/1986	1986/3, 1986/11	1963	E_{M}/1963	1963/3, 1963/5
1991	E_{S}/1991	1990/1, 1990/2, 1991/6, 1991/8	1964	E_{M}/1963→*L_{W}/1964	1963/3, 1963/5, 1964/11
1997	L_{W}/1996→E_{VS}/1997	-			

E represents El Niño, L represents La Niña, and the subscripts represent their magnitudes, which were categorized into five grades: extreme (E), very strong (VS), strong (S), moderate (M), and weak (W).The symbol '-' means that neither an El Niño/La Niña event nor a large volcanic eruption occurred.

* In 1964, El Niño lasted until March, then changed into a La Niña in April.

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Table 2. The probabilities of extreme events occurrences with ENSO events and large volcanic eruptions

Occurrence		Extreme drought	Extreme flood	No extreme drought/flood
Total number		29	28	208
ENSO in the previous year	El Niño	19 (65.5%)***	11 (39.3%)	79 (38.0%)
	La Niña	8 (27.6%)	9 (32.1%)	90 (43.3%)
	No El Niño/La Niña	2 (6.9%)	8 (28.6%)	39 (18.8%)
ENSO in the very year	El Niño	17 (58.6%)**	8 (28.6%)	82 (39.4%)
	La Niña	8 (27.6%)	13 (46.4%)	90 (43.2%)
	No El Niño/La Niña	4 (13.8%)	7 (25.0%)	36 (17.3%)
Large volcanic eruption in	the previous year	10 (34.4%)	11 (39.3%)	85 (40.9%)
	the very year	12 (41.4%)	12 (42.9%)	83 (39.9%)
	the very year or the previous year	17 (58.6%)	18 (64.3%)	129 (62.0%)
	No eruptions	12 (41.4%)	10 (35.7%)	79 (38.0%)

The significant level of Chi-test (χ^2), ***: p<0.01; **: p<0.05.