

Spatial and temporal changes of meteorological disasters in China during 1950–2013

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Abstract Flood, drought, hail, low temperature and frost disasters from low temperature and frost (DLTF), and snowstorm are the five main meteorological disasters (MDs) in China. Based on the collection of historical documents during 1950–2013 and official records between 2012 and 2013, this paper analyzed the temporal trends of affected area induced by MDs during 1950–2013 and the spatiotemporal characteristics of disaster frequency in recent 2 years in China. Besides, the direct economic losses and deaths caused by MDs were further discussed at a provincial level. Results showed that the affected area of MDs, especially flood, drought and DLTF significantly increased during the past 60 years. Flood was the most frequent disaster in China during 2012 and 2013, followed by hail. Spatial patterns of disaster frequency showed that there were more frequent floods in the middle and lower reaches of the Yellow River and the Yangtze River basin, droughts in central and southwest China, hails in north, northwest and southwest China, DLTFs and snowstorms in north, northwest China and individual areas in south China. However, the economic losses caused by MDs were higher in economically developed provinces, and the deaths were higher in mountain regions. Additionally, flood was the major disasters type that contributing to the most losses in most regions of China. These results play an important theoretical guiding role in meteorological disaster prediction, disaster prevention and reduction in the future.

Keywords Meteorological disasters · China · Frequency · Economic losses · Deaths

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1 Introduction

Meteorological disaster (MD) is one of the most deadly and costly natural disasters in the world (Xie et al. 2004; Liu and Yan 2011). In recent years, most of the Asian countries are experiencing more frequent MDs (e.g., floods, droughts, hurricanes, extreme heat or cold, snowstorms, etc.) as consequences of climate change and intensified human activities (Alcántara-Ayala 2002; Tall et al. 2013; Xu et al. 2013; Yang et al. 2013; Zhang et al. 2014b, c). These disasters greatly threatened people's lives, agricultural production, water resources and ecosystems (Salinger et al. 2000; Crompton and John McAneney 2008; Piao et al. 2010; Su et al. 2011; Tall et al. 2013; Yang et al. 2013; Zhang et al. 2014c).

Being located in the southeastern Eurasian Continent, the greatest continent in the world, and on the west shore of the Pacific Ocean, the world's largest ocean, China is affected by a typical monsoon climate. The annual precipitation varies from 25 mm in northwest China to more than 2,000 mm in southeast China (Wang and Fu 2013). Further, along with the dense population and explosive economic development, China is therefore one of the most severely affected countries by MDs in the world (Liu and Yan 2011; Zhang et al. 2014c). According to statistics, the economic losses resulted from MDs accounted for 1–3 % of the gross domestic production (GDP) (Liu and Yan 2011). Over the past several decades, China has experienced some devastating meteorological hazards. For instance, the great flood of 1998 inundated 21×10^6 ha of land and destroyed five million houses in the Yangtze River Basin, causing an economic loss of more than Chinese Yuan (CNY) 120 billion and at least 3,000 deaths (Piao et al. 2010; Xu et al. 2011). The unprecedented ice freezing and snow disasters of southern China in 2008, the worst in the past 50 years, resulted in direct economic loss up to CNY 160 billion and took away 162 lives (Gao 2009; Yang et al. 2013). Major recent catastrophic events, such as the severe rainstorm with a 100-year return period in North China on July 21, 2012 (The China Meteorological Administration 2012), the winter–spring continuous drought in southwest China during 2009–2013 (The China Meteorological Administration 2013a), and the strongest hot spells since 1951 in south China during summer 2013 (The China Meteorological Administration 2013b) had aroused great concern on MDs from various circles of society. Therefore, it is highly significant and urgent to analyze the characteristics of MDs in China.

Over the past several decades, there are many Chinese researchers or communities engaged in research into MDs. In 2005, the China Meteorological Administration started to publish “Yearbook of Meteorological Disasters in China”, in which the main disasters and their losses were recorded. Additionally, some researchers conducted related studies on disaster-forming environment analysis (Yin et al. 2009; Su et al. 2011), disaster risk assessment (Zhang 2004) and the impacts of MDs (Liu et al. 2013). Moreover, the economic loss evaluation (Liu and Yan 2011) and spatiotemporal characteristics of MDs (Xie et al. 2004; Zhao et al. 2010; Li et al. 2011; Wang et al. 2013; Yu et al. 2013; Zhang et al. 2014c) had been extensively discussed in many literatures. However, these studies were limited either on provincial or larger scales (Xie et al. 2004; Yu et al. 2013; Zhang et al. 2014b), or a specific disaster such as flood (Li et al. 2011), drought (Zhao et al. 2010; Yu et al. 2013), or thunderstorm (Wang et al. 2013). There are still very few comprehensive studies reported on MDs in the whole China. For example, whether the MD events have increasing trend, decreasing trend, or remaining stable under the background of climate change? How does the disaster distribute in space and time recently, what is the most vulnerable and sensitive area to MDs and what is the most devastating hazard type in different regions of China? These problems are all the most pressing problems in disaster risk assessment. To solve these problems, our main objectives are therefore as follows: (1) to analyze the temporal trends of MDs during

1950–2013; (2) to explore the spatiotemporal characteristics of MDs in 2012 and 2013; and (3) to identify the specific regions where MDs have a greater impact, and the major disaster type that contributing most to MD losses in different parts of China. Surely, our results will provide a scientific basis for governmental decision makers and local farmers to prevent and mitigate meteorological hazards in order to protect vulnerable ecosystems and to ensure agricultural security in China.

2 Data and methodology

Flood, drought, hail, DLTF (disasters from low temperature and frost) and snowstorm are the five main meteorological disaster types in China (Fang et al. 2011; Liu and Yan 2011; Guan et al. 2014). Typhoon was attributed to flood owing to its causing heavy storm. Therefore, this study was focused on the above-mentioned five disasters (flood, drought, hail, DLTF and snowstorm).

Based on the different research purposes, there are two categories of dataset used in this study. One is the long-term historical dataset, only including the affected areas of flood and drought during 1950–2013 and the affected area of hail and DLTF during 1978–2013 (the dataset did not contain information about snowstorm). They were, respectively, collected from the Bulletin of Flood and Drought Disasters in China (The Ministry of Water Resources of the People’s Republic of China 2013), and the Chinese Statistical Yearbook (National Bureau of Statistics of China 2013). The rough dataset was used to detect the long-term trends of the affected area of MDs during the past several decades.

The other dataset is the very detailed records of all MD events and its secondary disasters between 2012 and 2013, including disaster name, date, place, direct economic losses, affected population, deaths (including the missing persons), affected cropland area, failed cropland area, collapsed houses and damaged houses. They were collected from the official website of the Disaster Relief Division of Ministry of Civil Affairs of the People’s Republic of China (<http://preview.jzs.mca.gov.cn/article/zqkb/>). This dataset was used to investigate the spatiotemporal characteristics of MDs in recent 2 years. Such knowledge is essential for establishing the early warning system of meteorological hazards to reduce its economic losses and the number of deaths from disasters. Usually, the frequency, direct economic losses and deaths inflicted by disasters are the first priority to be considered for the assessment of natural hazards (Alcántara-Ayala 2002; Wei et al. 2004). Thus, we summarized the disaster frequencies at a city or county-level city and in each month during 2012 and 2013 to analyze the spatiotemporal distribution of MD frequencies. Besides, the direct economic losses and deaths were further investigated at the provincial level to identify the most severely affected areas by MDs and the major disaster type in different regions of China. It should be noted that Taiwan province (TW), Tibet Autonomous Region (XZ), Hong Kong (HK) and Macao (MC) were not included in analysis due to incomplete data.

3 Results and discussion

3.1 Trends of meteorological disasters during 1950–2013

Agriculture is inherently sensitive to climate conditions (Parry and Carter 1989). Annually, the MDs would cause a large number of crops to fail, seriously affecting the normal

production of agriculture which has a central role in ensuring the food security and welfare of 1.3 billion people in China (Piao et al. 2010). Therefore, the affected area of cropland was chosen as the major indicator to analyze the temporal trends of MDs during the past several years in this section.

Figure 1 shows the changing trends of affected area of flood, drought, hail and DLTF. Obviously, the affected area of flood and drought showed a statistically significant increasing trend ($p < 0.001$, $p = 0.026$) during 1950–2013 in China, but with large interannual variability. The increasing trend for that of flood became more pronounced since mid 1960s ($p < 0.001$). This was consistent with the finding of Fang et al. (2011). Many previous studies also indicated that some types of the extreme events, such as flood and drought, might be expected to occur more frequently in the future owing to the continuously global warming (Kharin and Zwiers 2000; Hegerl et al. 2004; Vincent et al. 2005; IPCC 2013). In contrast, the affected area of hail decreased significantly ($p = 0.002$) during 1978–2013. As global mean temperatures increase, there would be more frequent hot and fewer cold temperature extremes over most land areas (IPCC 2013). In addition, the number of frost days has been observed or projected in an obvious decreasing trend in most parts of China (Qian and Lin 2004; You et al. 2011). However, the affected area of DLTF did not show a decreasing trend correspondingly, but displayed a significant increasing trend ($p = 0.005$). This is because the total cultivated area of crop in China increased as climate warms (Fang et al. 2011). The affected area induced by DLTF was accordingly increasing. In summary, the impacts of MDs, especially flood, drought and DLTF on agriculture became worsening in China during the past several decades. Zhang et al. (2014c) suggested that it would become more possible for more types of disasters to occur, or several disasters occurring simultaneously in an individual area in the future. Therefore, developing strategies for disaster prevention and mitigation in the context of climate change is urgently demanded.

3.2 The main meteorological disasters and its losses in 2012 and 2013

During 2012 and 2013, China suffered from a succession of meteorological disaster events. For instance, southwestern China was seriously affected by drought in early 2012, but several rainstorms in rainy season (Guan et al. 2014). In May 10, 2012, a severe flash flood and mudslide burst across Min County, Gansu Province, resulting in more than 70 deaths (Guan et al. 2014). In July 21, 2012, Beijing was subjected to an unprecedented storm. The total economic losses were estimated at CNY 11 billion and more than 79 people lost their lives (The China Meteorological Administration 2012). And then, six typhoons named “Vicente”, “Sura”, “Davi”, “Haikui”, “Qide” and “Libra” successively landed in coastal China during July 24 and August 24, 2012, which was exceedingly rare in the historical records since 1949 (Guan et al. 2014). During June 1 and July 11, 2013, heavy rainfall successively attacked Sichuan province five times altogether, claiming at least 200 lives. The accumulated rainfall in Dujiang Dam reached up to 1,151 mm during July 1 and 11 (The China Meteorological Administration 2013c). In summer 2013, the strongest hot spells since 1951 swept across south China. Regional average rainfall from July 1 to Aug. 21 was 135.2 mm, the lowest for the same period in recent 60 years. Persistent heat wave and lack of rain resulted in severe droughts, which caused a direct economic loss of over CNY 48 billion (The China Meteorological Administration 2013b). During November 16 and 20, 2013, northeast China was hit by a severe snowstorm. The snow depth reached up to 10–40 mm in east-central Heilongjiang and Jilin province, with the maximum of 64 mm in Shangzhi city (The China Meteorological Administration 2013d). The above-mentioned

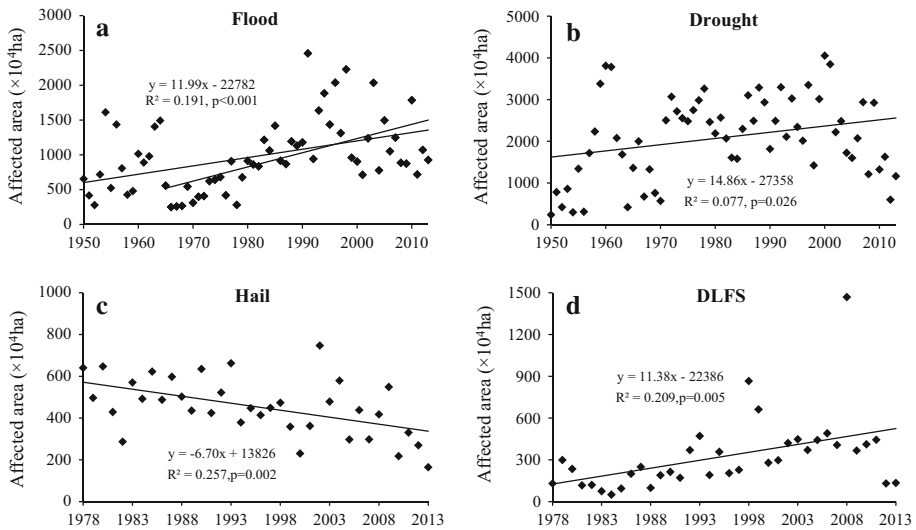


Fig. 1 Changing trends of affected area of flood (a), drought (b), Hail (c), and DLTF (d) during 1950–2013. DLTF means disaster from low temperature and frost. The regression line was obtained by the least square method

events were comparatively typical disasters in recent 2 years. The detailed information of MDs and its related losses during 2012 and 2013 are summarized in Table 1.

In total, there were 676 reported MD events in China during 2012, causing a direct economic loss of about CNY 217 billion and 1,472 deaths (Table 1). The affected population was approximately 248 million, equivalent to 20 % of China’s total population. The affected area of crops was $2,086 \times 10^4$ ha, accounting for 12.8 % of the total cultivated area in China (National Bureau of Statistics of China 2013). Flood was the most frequent and severe disaster among all disaster types in 2012, with the frequencies, economic losses and deaths accounting for 53, 74 and 79 % of the totals. The second-ranked was hail. Drought had the lowest frequency, only representing 4 % of the totals. But its losses far exceeded those of DLTF and snowstorm owing to the long duration, widespread affected area and far-reaching consequences of drought.

In 2013, the impacts of MDs were more severe than those in 2012 (Table 1). The total frequencies decreased, but the affected population, losses from crops and houses as well as economy all increased compared with 2012. Flood was still the most common and deadliest disasters in 2013 and followed by drought. The losses induced by hail were significantly alleviated. Overall, flood, drought and hail were the top three disasters in China in recent 2 years.

3.3 Spatiotemporal distribution of meteorological disaster frequencies in 2012 and 2013

3.3.1 Spatial distribution of meteorological disaster frequencies

Figures 2 and 3 showed the spatial distribution of MD frequencies in 2012 and 2013, respectively. It clearly indicated that different types of disasters had unique spatial

Table 1 Summary of the main meteorological disasters in China during 2012 and 2013

Year	Disaster	Population		Crop		House		Direct economic loss (billion CNY)	Frequency (time/year)
		Affected (million)	Death (person)	Affected area ($\times 10^4$ ha)	Failed area ($\times 10^4$ ha)	Collapsed house ($\times 10^4$)	Damaged house ($\times 10^4$)		
2012	Flood	158.08	1,162	1,071.92	128.82	67	225.74	160.39	359
	Drought	55.82		601.85	48.30			17.90	29
	Hail	28.68	281	270.73	33.96	19.31	44.73	31.20	220
	DLTF	3.25		131.34	13.51	0.24	2.70	5.60	30
	Snowstorm	1.73	29	10.40	0.59		0.59	1.86	38
	Total	247.55	1,472	2,086.24	225.18	86.55	273.76	216.96	676
2013	Flood	117.98	1,349	927.56	134.99	38.00	134.14	194.33	333
	Drought	116.11		1,166.07	135.37			58.14	23
	Hail	17.64	192	165.21	19.19	1.24	61.19	14.43	193
	DLTF	13.41	2	134.70	19.15	0.05	0.02	14.06	38
	Snowstorm	3.99	7	19.23	2.77	0.35	0.56	1.68	14
	Total	269.12	1,550	2,412.77	311.46	39.64	195.91	282.63	601

DLTF disaster from low temperature and frost

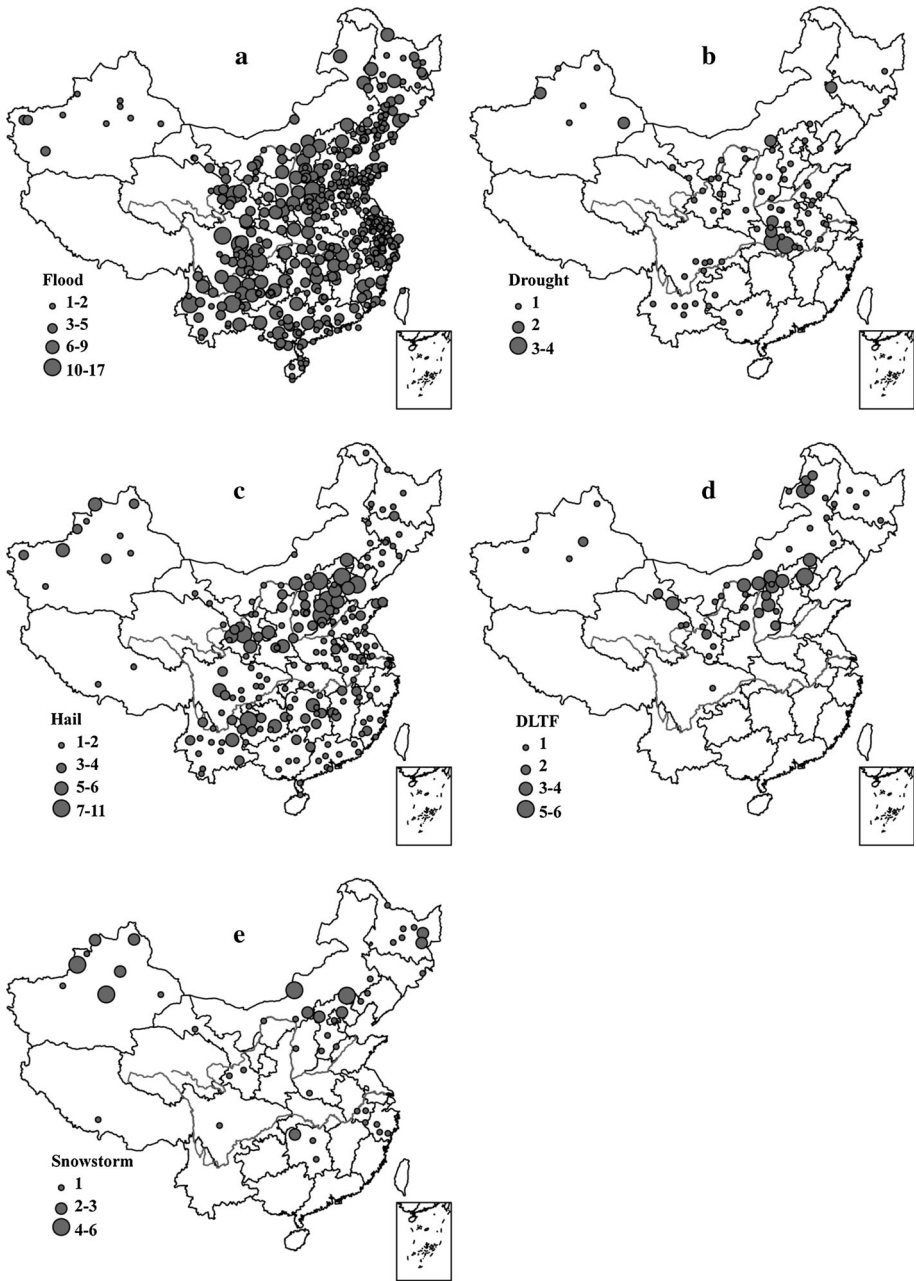


Fig. 2 Spatial distribution of flood (a), drought (b), Hail (c), DLTF (d) and snowstorm (e) frequency in China within 2012

characteristics. Flood was the most widely distributed disaster in China among the five types (Figs. 2a, 3a). The middle and lower reaches of the Yellow River and the Yangtze River basin usually suffered more frequent floods. This finding confirmed that of Su et al.

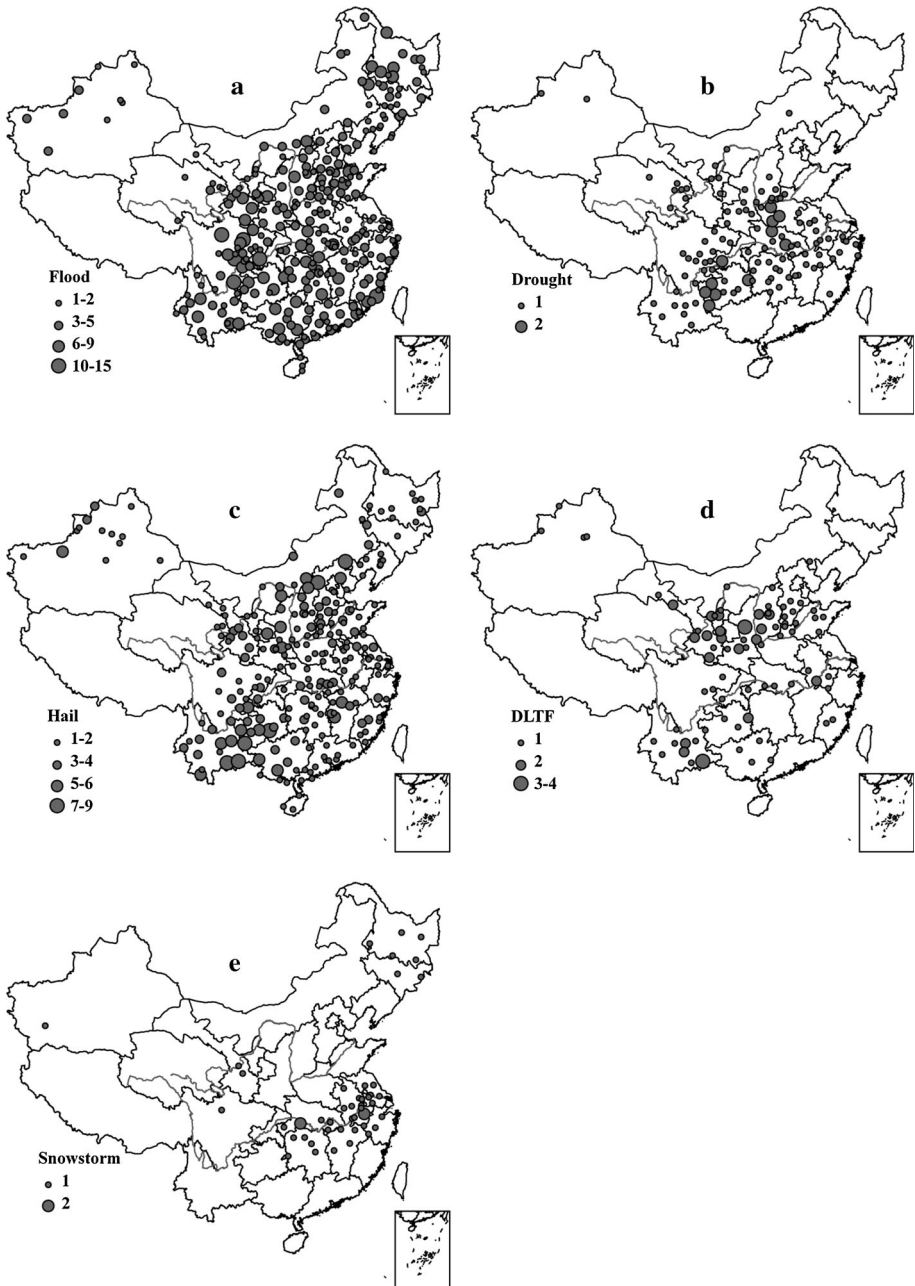


Fig. 3 Spatial distribution of flood (a), drought (b), Hail (c), DLTF (d) and snowstorm (e) frequency in China within 2013

(2008) who indicated that flood disaster might be aggravated in the incoming decade of the twenty-first century in the Yangtze River basin. The maximum 5-day precipitation, an indicator of flood-producing events, was also projected to increase over the Yangtze River

basin in the twenty-first century (Xu et al. 2009). In the Yellow River basin, many studies found that the total precipitation showed a declining trend during the past several decades, but the extreme precipitation intensity increased from west to east (Liu et al. 2008; Huang et al. 2009; Zhang et al. 2014a). This implies that the total precipitation during one single rainfall event increased. Such precipitation patterns could explain why the middle and lower Yellow River also suffered more frequent floods in China, indicating the strong association between climatic condition and MD frequencies.

Drought occurred sporadically in north, central and southwest China, and the west of northwest China in 2012, with the highest frequency in Hubei province (Fig. 2b). But in 2013, the most frequent drought occurred in southwest and central China, while, surprisingly, northwest China has enjoyed less droughts (Fig. 3b). It is predicted that wetter northwest China may further intensify under the IPCC A1B scenario (Piao et al. 2010). Southwest China was a moist area in the past, but since 2009 most parts of southwest China

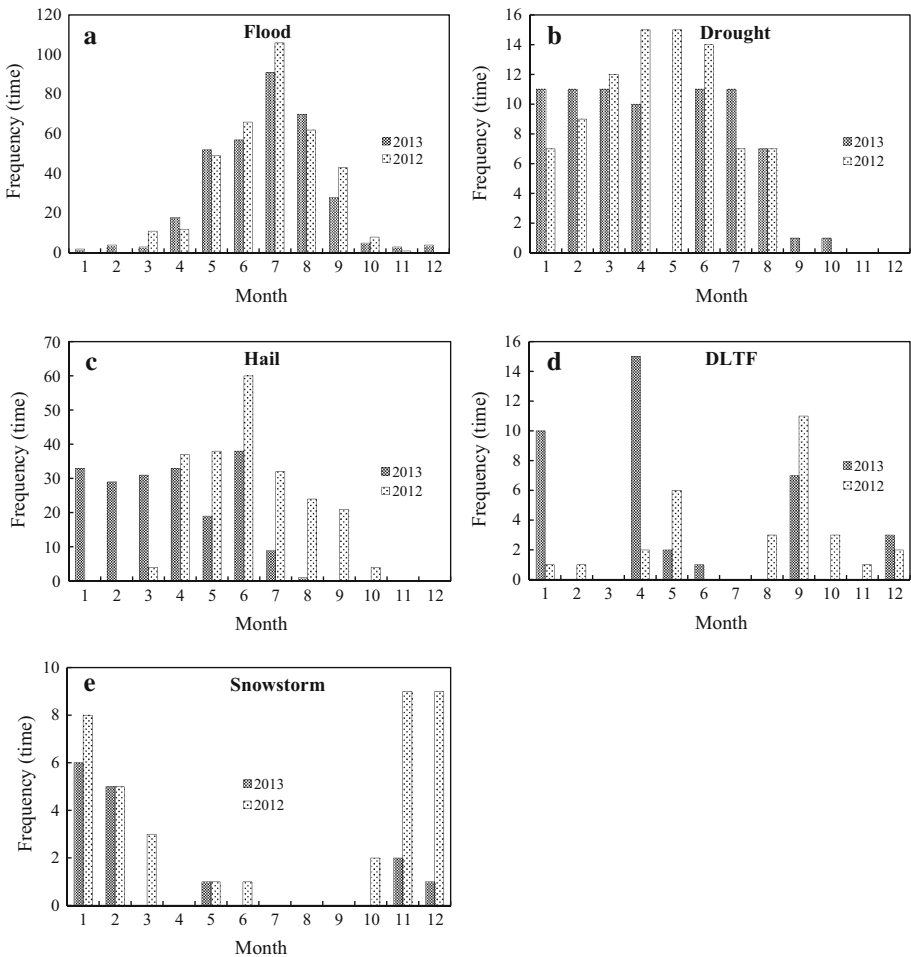
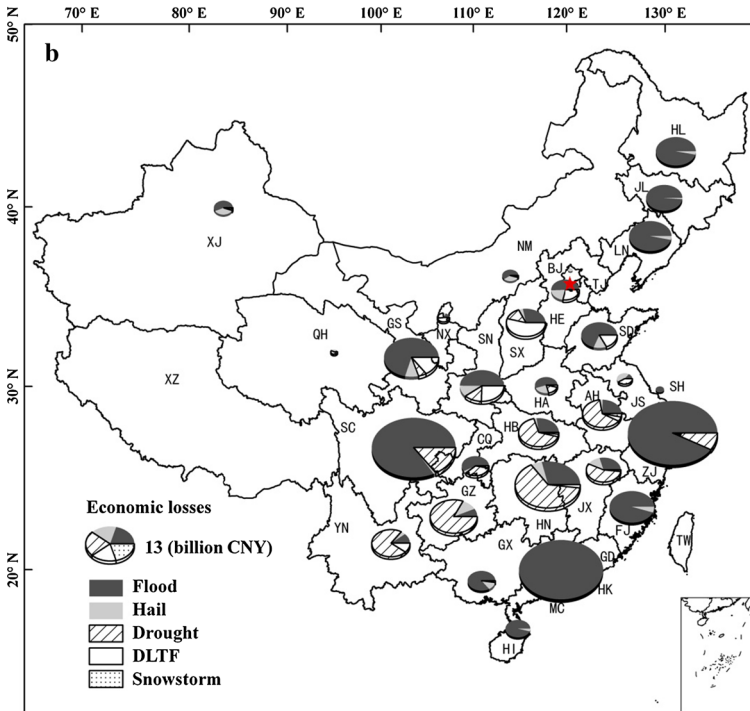
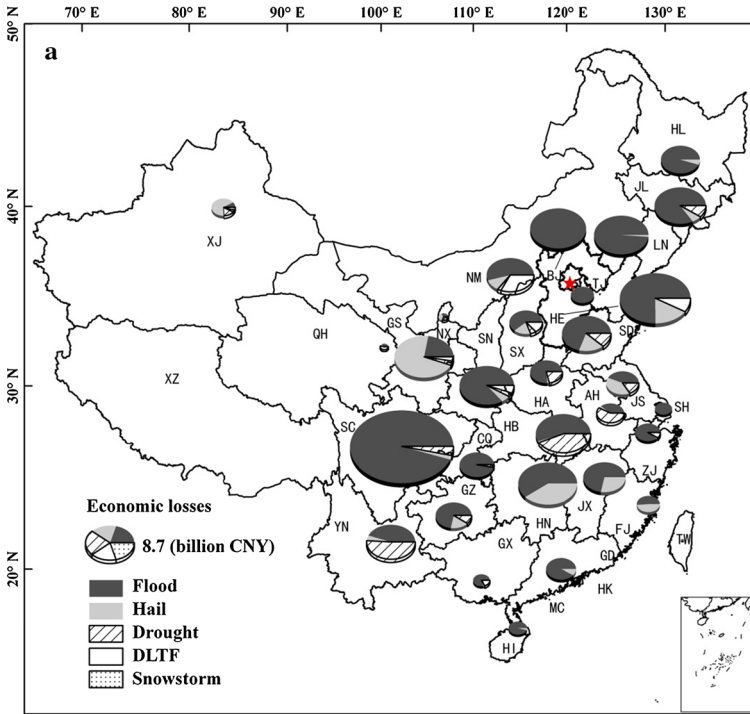


Fig. 4 Monthly distributions of flood (a), drought (b), Hail (c), DLTF (d) and snowstorm (e) frequency in China during 2012 and 2013



◀ **Fig. 5** Spatial distribution of economic losses and structure of meteorological disasters in China within 2012 (a) and 2013 (b)

suffered from sustained drought from autumn to next spring. Many researchers ascribed this phenomenon to the variations of precipitation patterns (Zhang et al. 2014a). In southwest China, the decrease in annual number of raindays is coincident with an increase in annual precipitation (Piao et al. 2010; Li et al. 2012), implying more extreme flood or drought. Yu et al. (2013) found that the chances of regional drought in Yunnan province significantly increased with warming temperatures, but the interaction mechanism remains unexplained.

Hail was also a disaster that occurred frequently in China, especially in north, northwest and southwest China (Figs. 2c, 3c). This is in line with the distribution of two big hail zones in China (Guan et al. 2014). The southern hail zone includes southwest and central China. The northern hail zone consists of northwest, north and northeast China, which is the widest and longest hail zone.

Compared with the above-mentioned disasters, DLTF and snowstorm had relatively lower frequency in China, and the affected areas were much smaller. In 2012, both DLTF and snowstorm occurred principally in northeast, north and northwest China (Fig. 2d, e). However, in 2013, some regions in southern China also suffered DLTF, especially Yunnan province (Fig. 3d). And snowstorm was mainly distributed in central and east China (Fig. 3e). The completely different spatial patterns of snowstorm in 2012 and 2013 reflected the instability of climatic change (Moonen et al. 2002; Vergni and Todisco 2010). Such climate instability would in turn lead to an increase in meteorological disaster events such as rainstorm, drought and hail.

3.3.2 Monthly variations of meteorological disaster frequencies

Figure 4 shows the monthly distribution of MDs in 2012 and 2013. As shown in Fig. 4a, flood happened almost in every month, but the frequencies were not uniformly distributed throughout the year. After April, the flood frequency was of a clear upward trend in both 2012 and 2013 and reached a peak in July. There were in total 234 (218) floods during June, July and August in 2012 (2013), accounting for 65 % of the total frequency in a year, implying the obvious seasonality of precipitation in China (Wang and Zhou 2005; Zhang et al. 2009). As for drought (Fig. 4b), the most prominent characteristic was long duration, with roughly the same frequency from January to August. This disaster usually had a greater impact on agriculture during March–July because this period is crucial for agricultural production activities due to crops being susceptible to drought (Yu et al. 2013; Guan et al. 2014). In 2012, hail was more frequent from April to June, and mainly concentrated in June (Fig. 4c). In 2013, the frequency exhibited a relatively stable state from January to June, but the highest frequency also occurred in June. As for DLTF, the monthly distribution between the 2 years was very different (Fig. 4d). The most frequent DLTF in 2012 and 2013 occurred in September and April, respectively. Snowstorm occurred mainly in November, December, January and April in both 2012 and 2013 (Fig. 4e).

3.4 Spatial distribution of meteorological disasters losses in 2012 and 2013

It is clearly that the ability of local people or communities to cope with and recover from disasters varies from region to region (IPCC 2012). Therefore, the losses induced by MDs

are obviously different across different geographical areas. In this section, the total direct economic losses and deaths were investigated at a provincial level to identify the most severely affected area by MDs. In addition, we classified the economic losses and deaths by disaster type to find the major disaster type that contributing most to the total losses.

Table 2 Abbreviation of provinces, autonomous regions, municipalities and special administrative regions in China

Name (in alphabetical order)	Abbreviation
<i>Province</i>	
Anhui	AH
Fujian	FJ
Gansu	GS
Guangdong	GD
Guizhou	GZ
Hainan	HI
Hebei	HE
Henan	HA
Heilongjiang	HL
Hubei	HB
Hunan	HN
Jilin	JL
Jiangsu	JS
Jiangxi	JX
Liaoning	LN
Qinghai	QH
Shandong	SD
Shanxi	SX
Shaanxi	SN
Sichuan	SC
Taiwan	TW
Yunnan	YN
Zhejiang	ZJ
<i>Autonomous region</i>	
Ningxia Hui autonomous region	NX
Xizang autonomous region	XZ
Xinjiang Uygur autonomous region	XJ
Inner Mongolia autonomous region	NM
Guangxi Zhuang autonomous region	GX
<i>Municipality</i>	
Beijing	BJ
Chongqing	CQ
Shanghai	SH
Tianjin	TJ
<i>Special administrative region</i>	
Macao	MC
Hong Kong	HK

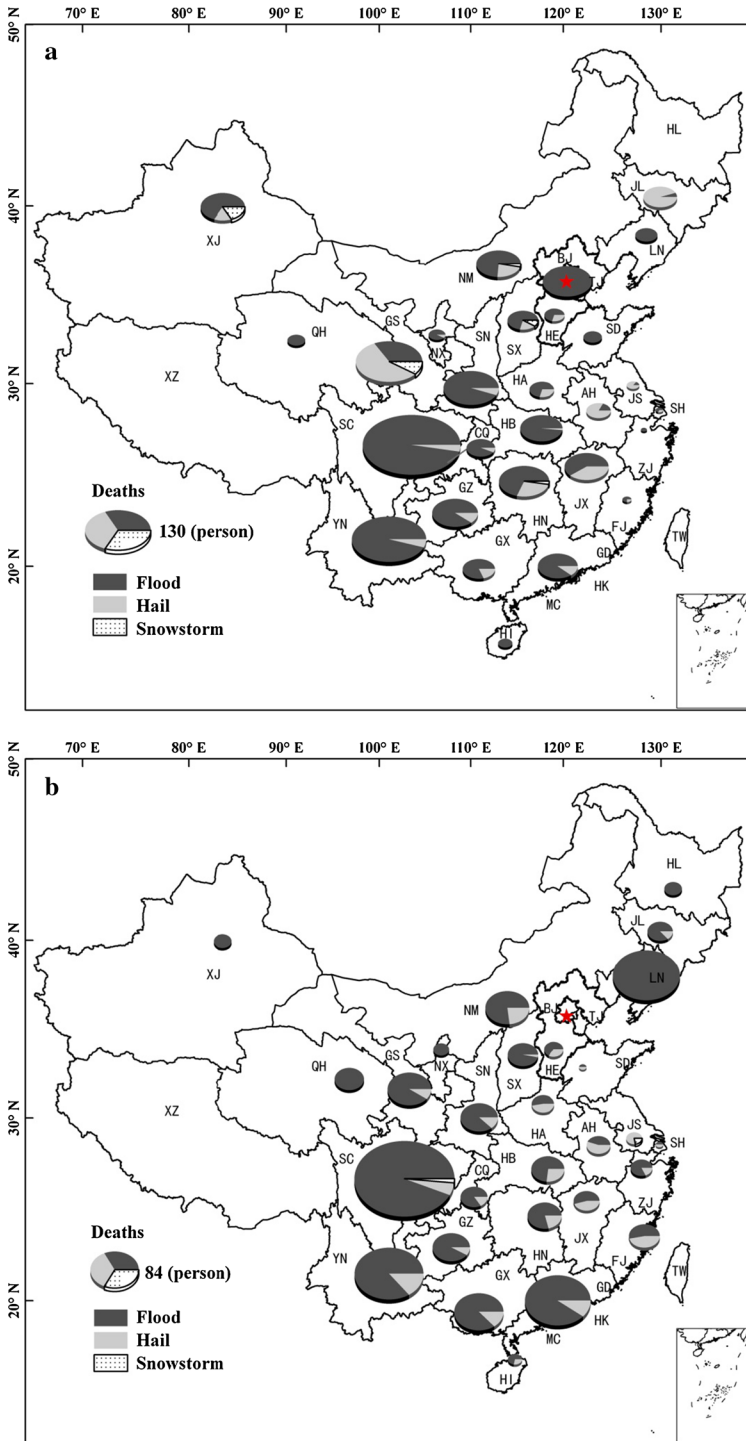


Fig. 6 Spatial distribution of deaths and structure of meteorological disasters in China within 2012 (a) and 2013 (b)

From Fig. 5, it can be seen that the economic losses showed different characteristic among different provinces. In 2012, the most serious province affected by MDs was Sichuan (SC, see Table 2 for the abbreviations) province, with a direct economic loss of CNY 39.09 billion, followed by Hebei and Hunan (HE and HN) province (Fig. 5a). By contrast, the northwest and southeast coastal provinces suffered less economic losses. In 2013, Zhejiang (ZJ) province suffered the greatest economic loss of CNY 42.26 billion owing to the typhoon named “Fitter” (Fig. 5b). According to statistics, the heavy rainfall induced by “Fitter” caused economic losses of CNY 37.89 billion in ZJ province, accounting for 90 % of the total losses in a year (The Ministry of Civil Affairs of the People’s Republic of China 2013). Guangdong (GD) and SC province came in second and third position, respectively. Additionally, different types of disasters had different contributions to the total economic losses among different regions of China (Fig. 5). In general, the economic losses induced by flood accounted for a substantial part of the totals in most provinces of China during the 2 years. However, in Xinjiang Uygur Autonomous Region (XJ) and Gansu (GS) province, the economic losses caused by hail were the highest among five types of disasters in 2012, accounting for 64 and 73 % of the totals, respectively (Fig. 5a). In central and southwest China, such as Yunnan (YN), Guizhou (GZ), HN, HB, Jiangxi (JX) and Anhui (AH) provinces, the economic losses were mainly attributed to drought in 2013 (Fig. 5b). Besides, DLTF contributed to the most economic losses in Shanxi (SX) province.

The deaths caused by MD in 2012 were mainly distributed in central and west China (Fig. 6a). Regionally, the highest number of fatalities was in SC province with at least 260 deaths, followed by Yunnan (YN), GS, Shaanxi (SN) and HN province. The deaths of above five provinces accounted for 50 % of the total deaths in China. In 2013, the deaths in SC province were still the most, with an amount of 358 deaths, while those in YN and Liaoning (LN) province were ranked second and third place, respectively (Fig. 6b). The results also showed that flood was without doubt the deadliest disaster in most provinces in 2012 and 2013 (Fig. 6). It is noteworthy that hail contributed to the most deaths in GS, AH, Jiangsu (JS) and Jilin (JL) provinces in 2012 (Fig. 6a). The percentage in these provinces was 57, 83, 86 and 95 %, respectively. Similar situation also occurred in AH and JS provinces in 2013 (Fig. 6b).

In general, the economic losses caused by MDs were higher in economically developed provinces, e.g., SC ZJ, GD, HE and HN (Fig. 5). However, the deaths were higher in mountain regions, e.g., SC and YN province where topography is complex and population is unevenly distributed (Fig. 6). Therefore, the severity of meteorological hazards depends not only on the disaster frequency but also strongly on the region’s geographical features, population distribution and the socioeconomic development—that is the level of the exposure and vulnerability to these disasters.

4 Concluding remarks

The temporal trends of affected area resulting from MDs in China during 1951–2013, spatiotemporal characteristics of MD frequencies and spatial distribution of disaster losses and deaths in 2012 and 2013 were analyzed in this study. The affected area of flood, drought and DLTF showed a significant upward trend during 1951–2013, while that of hail showed a significant downward trend. The frequencies of different disasters had unique spatiotemporal characteristics. Geographically, flood mainly occurred in the middle and lower reaches of the Yellow River and the Yangtze River basin; drought was observed at a

higher frequency in central and southwest China; hail was principally distributed in north, northwest and southwest China; DLTF and snowstorm were more frequent in north, northwest China and individual areas in south China. On temporal scale, there were more frequent floods in June–August, droughts in January–August, hails in April–June, DLTFs in April and September, and Snowstorms in November–February. The results also demonstrated that MDs had a greater impact in provinces such as SC, YN, GD, HN, GS, ZJ and HE in terms of the direct economic losses and deaths. Besides, flood was the major disasters type that contributing to the most losses and deaths in most regions of China. Sometimes drought also accounted for a substantial part of the total losses in YN, GZ, HN, HB, JX and AH province, and so did hail in XJ, GS, AH, JS and JL province.

The results will have some certain directive significance for meteorological disaster prediction, disaster prevention and reduction further in the future. Among the five MD types, flood prevention and mitigation is of uppermost priority almost in the whole China. Besides, more attention and effort should be paid to cope with not only flood but also drought in these provinces such as YN, GZ, HN, HB, JX and AH. Additionally, we should attach primary importance to both flood and hail in provinces such as XJ, GS, AN, JS and JL. Consequently, it is critical and necessary for the development of different strategies and practices to prevent and mitigate meteorological hazards according to its latest characteristics in different parts of China. Our future research focuses on establishing the early warning management system of MDs at the national level under the background of climate change.

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References

- Alcántara-Ayala I (2002) Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. *Geomorphology* 47(2–4):107–124. doi:[10.1016/S0169-555X\(02\)00083-1](https://doi.org/10.1016/S0169-555X(02)00083-1)
- Crompton RP, John McAneney K (2008) Normalised Australian insured losses from meteorological hazards: 1967–2006. *Environ Sci Policy* 11(5):371–378. doi:[10.1016/j.envsci.2008.01.005](https://doi.org/10.1016/j.envsci.2008.01.005)
- Fang SB, Yang JJ, Zhou GS (2011) Change trend and distributive characteristics of agrometeorological disasters in China in recent 30 years. *J Nat Disasters* 20(5):69–73 (In Chinese)
- Gao H (2009) China's snow disaster in 2008, who is the principal player? *Int J Climatol* 29(14):2191–2196. doi:[10.1002/joc.1859](https://doi.org/10.1002/joc.1859)
- Guan YH, Wang B, Zheng FL, Zhang P, Qin C (2014) Characteristics of meteorological disasters in China during 2012. *J Nat Disasters* 23(1):24–31 (In Chinese)
- Hegerl GC, Zwiers FW, Stott PA, Kharin VV (2004) Detectability of anthropogenic changes in annual temperature and precipitation extremes. *J Clim* 17(19):3683–3700. doi:[10.1175/1520-0442\(2004\)0172.0.CO;2](https://doi.org/10.1175/1520-0442(2004)0172.0.CO;2)
- Huang Y, Cai JL, Yin H, Cai MT (2009) Correlation of precipitation to temperature variation in the Huanghe River (Yellow River) basin during 1957–2006. *J Hydrol* 372(1–4):1–8. doi:[10.1016/j.jhydrol.2009.03.029](https://doi.org/10.1016/j.jhydrol.2009.03.029)
- IPCC (2012) Managing the risks of extreme events and disasters to advance climate change adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA
- IPCC (2013) Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA
- Kharin VV, Zwiers FW (2000) Changes in the extremes in an ensemble of transient climate simulations with a coupled atmosphere–ocean GCM. *J Clim* 13(21):3760–3788. doi:[10.1175/1520-0442\(2000\)0132.0.CO;2](https://doi.org/10.1175/1520-0442(2000)0132.0.CO;2)

- Li JB, Hu W, YIN H, Mao DH, Zeng FM, Deng CX, Dai Y (2011) Evolutive characteristics and differentiation rules of agricultural flood in Dongting Lake Basin from 1950–2009. *J Nat Resour* 26(9):1496–1505 (In Chinese)
- Li ZX, He YQ, Wang PY et al (2012) Changes of daily climate extremes in southwestern China during 1961–2008. *Global Planet Change* 80–81:255–272. doi:10.1016/j.gloplacha.2011.06.008
- Liu T, Yan TC (2011) Main meteorological disasters in China and their economic losses. *J Nat Disasters* 20(2):90–95 (In Chinese)
- Liu Q, Yang ZF, Cui BS (2008) Spatial and temporal variability of annual precipitation during 1961–2006 in Yellow River Basin, China. *J Hydrol* 361(3–4):330–338. doi:10.1016/j.jhydrol.2008.08.002
- Liu XF, Zhang Z, Shuai JB, Wang P, Shi WJ, Tao FL, Chen Y (2013) Impact of chilling injury and global warming on rice yield in Heilongjiang Province. *J Geogr Sci* 23(1):85–97. doi:10.1007/s11442-013-0995-9
- Moonen AC, Ercoli L, Mariotti M, Masoni A (2002) Climate change in Italy indicated by agrometeorological indices over 122 years. *Agric For Meteorol* 111(1):13–27. doi:10.1016/S0168-1923(02)00012-6
- National Bureau of Statistics of China (2013) Chinese statistical yearbook. China Statistics Press, Beijing
- Parry ML, Carter TR (1989) An assessment of the effects of climatic change on agriculture. *Clim Change* 15:95–116
- Piao SL, Ciais P, Huang Y et al (2010) The impacts of climate change on water resources and agriculture in China. *Nature* 467:43–50. doi:10.1038/nature09364
- Qian WH, Lin X (2004) Regional trends in recent temperature indices in China. *Clim Res* 27(2):119–134. doi:10.1007/s00703-004-0101-z
- Salinger MJ, Stigter CJ, Das HP (2000) Agrometeorological adaptation strategies to increasing climate variability and climate change. *Agric For Meteorol* 103(1–2):167–184. doi:10.1016/S0168-1923(00)00110-6
- Su BD, Gemmer M, Jiang T (2008) Spatial and temporal variation of extreme precipitation over the Yangtze River Basin. *Quat Int* 186(1):22–31. doi:10.1016/j.quaint.2007.09.001
- Su W, Zhang XD, Wang Z, Su XH, Huang JX, Yang SQ, Liu SC (2011) Analyzing disaster-forming environments and the spatial distribution of flood disasters and snow disasters that occurred in China from 1949 to 2000. *Math Comput Modell* 54(3–4):1069–1078. doi:10.1016/j.mcm.2010.11.037
- Tall A, Patt AG, Fritz S (2013) Reducing vulnerability to hydro-meteorological extremes in Africa. A qualitative assessment of national climate disaster management policies: accounting for heterogeneity. *Weather Clim Extrem* 1:4–16
- The China Meteorological Administration (2012) China's top ten weather climate events in 2012. China Weather Web. http://www.weather.com.cn/news/1752116_3.shtml. Accessed 24 June 2014
- The China Meteorological Administration (2013a) China's top ten weather climate events in 2013. China Weather Web. http://www.weather.com.cn/news/2013/11/2011013_13.shtml. Accessed 24 June 2014
- The China Meteorological Administration (2013b) China's top ten weather climate events in 2013. China Weather Web. http://www.weather.com.cn/news/2013/11/2011013_3.shtml. Accessed 24 June 2014
- The China Meteorological Administration (2013c) China's top ten weather climate events in 2013. China Weather Web. <http://www.weather.com.cn/news/2013/11/2011013.shtml>. Accessed 24 June 2014
- The China Meteorological Administration (2013d) China's top ten weather climate events in 2013. China Weather Web. http://www.weather.com.cn/news/2013/11/2011013_14.shtml. Accessed 24 June 2014
- The Ministry of Civil Affairs of the People's Republic of China (2013) Fitter continuously affect Zhejiang province. Disaster Relief Division. <http://preview.jzs.mca.gov.cn/article/zqkb/zqhz/201310/20131000528019.shtml>. Accessed 24 June 2014
- The Ministry of Water Resources of the People's Republic of China (2013) Bulletin of flood and drought disasters in China. China Water Power Press, Beijing
- Vergni L, Todisco F (2010) Spatio-temporal variability of precipitation, temperature and agricultural drought indices in Central Italy. *Agric For Meteorol* 151(3):301–313. doi:10.1016/j.agrformet.2010.11.005
- Vincent LA, Peterson TC, Barros VR et al (2005) Observed trends in indices of daily temperature extremes in North America 1960–2000. *J Clim* 18:5011–5023. doi:10.1175/JCLI3589.1
- Wang AH, Fu JJ (2013) Changes in daily climate extremes of observed temperature and precipitation in China. *Atmos Ocean Sci Lett* 6:312–319. doi:10.3878/j.issn.1674-2834.12.0106
- Wang Y, Zhou L (2005) Observed trends in extreme precipitation events in China during 1961–2001 and the associated changes in large-scale circulation. *Geophys Res Lett* 32(9):L09707. doi:10.1029/2005GL022574
- Wang ZK, Sun GD, Yan WG, Wei DL, Zhang DQ (2013) Study on the distribution characteristics of thunderstorms in Xuzhou City. *Meteorol Environ Res* 4(11):32–34
- Wei YM, Fan Y, Lu C, Tsai HT (2004) The assessment of vulnerability to natural disasters in China by using the DEA method. *Environ Impact Assess Rev* 24(4):427–439. doi:10.1016/j.eiar.2003.12.003

- Xie ME, Cheng JG, Fan B (2004) Spatiotemporal distribution features of meteorological disasters in Yunnan. *J Nat Disasters* 13(5):40–47 (In Chinese)
- Xu Y, Xu CH, Gao XJ, Luo Y (2009) Projected changes in temperature and precipitation extremes over the Yangtze River Basin of China in the 21st century. *Quat Int* 208(1–2):44–52. doi:[10.1016/j.quaint.2008.12.020](https://doi.org/10.1016/j.quaint.2008.12.020)
- Xu X, Du YG, Tang JP, Wang Y (2011) Variations of temperature and precipitation extremes in recent two decades over China. *Atmos Res* 101(1–2):143–154. doi:[10.1016/j.atmosres.2011.02.003](https://doi.org/10.1016/j.atmosres.2011.02.003)
- Xu YP, Zhang XJ, Ran QH, Tian Y (2013) Impact of climate change on hydrology of upper reaches of Qiantang River Basin, East China. *J Hydrol* 483:51–60. doi:[10.1016/j.jhydrol.2013.01.004](https://doi.org/10.1016/j.jhydrol.2013.01.004)
- Yang JS, Sun HY, Wang L, Li LB, Wu B (2013) Vulnerability evaluation of the highway transportation system against meteorological disasters. *Procedia Soc Behav Sci* 96:280–293. doi:[10.1016/j.sbspro.2013.08.035](https://doi.org/10.1016/j.sbspro.2013.08.035)
- Yin YX, Xu YP, Chen Y (2009) Relationship between flood/drought disasters and ENSO from 1857 to 2003 in the Taihu Lake basin, China. *Quat Int* 208(1–2):93–101. doi:[10.1016/j.quaint.2008.12.016](https://doi.org/10.1016/j.quaint.2008.12.016)
- You Q, Kang SC, Aguilar E et al (2011) Changes in daily climate extremes in China and their connection to the large scale atmospheric circulation during 1961–2003. *Clim Dyn* 36(11–12):2399–2417. doi:[10.1007/s00382-009-0735-0](https://doi.org/10.1007/s00382-009-0735-0)
- Yu WJ, Shao MY, Ren ML, Zhou HJ, Jiang ZH, Li DL (2013) Analysis on spatial and temporal characteristics drought of Yunnan Province. *Acta Ecologica Sinica* 33(6):317–324. doi:[10.1016/j.chnaes.2013.09.004](https://doi.org/10.1016/j.chnaes.2013.09.004)
- Zhang JQ (2004) Risk assessment of drought disaster in the maize-growing region of Songliao Plain, China. *Agric Ecosyst Env* 102(2):133–153. doi:[10.1016/j.agee.2003.08.003](https://doi.org/10.1016/j.agee.2003.08.003)
- Zhang Q, Xu CY, Zhang Z, Chen YD, Liu CL (2009) Spatial and temporal variability of precipitation over China, 1951–2005. *Theor Appl Climatol* 95(1–2):53–68. doi:[10.1007/s00704-007-0375-4](https://doi.org/10.1007/s00704-007-0375-4)
- Zhang Q, Peng JT, Singh VP, Li JF, David Chen YQ (2014a) Spatio-temporal variations of precipitation in arid and semiarid regions of China: the Yellow River basin as a case study. *Global Planet Change* 114:38–49. doi:[10.1016/j.gloplacha.2014.01.005](https://doi.org/10.1016/j.gloplacha.2014.01.005)
- Zhang Z, Wang P, Chen Y, Zhang S, Tao FL, Liu XF (2014b) Spatial pattern and decadal change of agrometeorological disasters in the main wheat production area of China during 1991–2009. *J Geogr Sci* 24(3):387–396. doi:[10.1007/s11442-014-1095-1](https://doi.org/10.1007/s11442-014-1095-1)
- Zhang Z, Chen Y, Wang P, Zhang S, Tao FL, Liu XF (2014c) Spatial and temporal changes of agrometeorological disasters affecting maize production in China since 1990. *Nat Hazards* 71(3):2087–2100. doi:[10.1007/s11069-013-0998-y](https://doi.org/10.1007/s11069-013-0998-y)
- Zhao HY, Zhang Q, Gao G, Lu E (2010) Characteristic analysis of agricultural drought disaster in China during 1951–2007. *J Nat Disasters* 19(4):201–206 (In Chinese)