Clim. Past, 20, 2455–2471, 2024
https://doi.org/10.5194/cp-20-2455-2024

Climate of the Past
Open Access

Processes, spatial patterns, and impacts of the 1743 extreme-heat event in northern China: from the perspective of historical documents

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Received: 14 January 2024 – Discussion started: 25 January 2024
Revised: 20 August 2024 – Accepted: 17 September 2024 – Published: 8 November 2024

Abstract. The study of historical extreme heat is helpful for understanding modern heatwaves. By collecting 63 historical documents from three kinds of historical materials and using text analysis methods based on keywords, grading, and classification, this research recovered and analysed the processes of extreme heat over time, the spatial patterns of heat severity, and the impacts of extreme heat in northern China during 1743. The results show the following. (1) The extreme heat of 1743 began to be noticed by people on 22 June; began to kill people on 14 July; and was at its most severe, attracting great attention from the central government, between 14 and 25 July. (2) Extreme heat occurred on the plains of the provinces of Hebei and Shandong and in the valleys of southwestern Shanxi. Areas of the plains east of the Taihang Mountains, such as Baoding, Shijiazhuang, and Xingtai, experienced the worst heat. These areas are also at high risk for heatwaves on the North China Plain in modern times. (3) In 1743, heat affected people, animals, plants, and facilities and had the most severe impact on human deaths. The death toll in a single county reached dozens in a single day. Timely cooling and reducing exposure have been limited but necessary means of addressing extreme heat in both ancient and modern times.

1 Introduction

In the context of global warming, extreme heat and heatwave events, as well as their impacts on human societies, have received increased amounts of attention and research. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded that as anthropogenic global warming intensifies, there is a high probability that the intensity and frequency of extreme weather events will continue to increase (IPCC, 2021). Future heatwaves are expected to be more intense, more frequent, and longer lasting (Meehl and Tebaldi, 2004; IPCC, 2013; Han et al., 2022). Extreme heat, as a weather hazard, poses a significant threat to human life and health, as well as to socioeconomics, by reducing agricultural yields, stressing health systems, decreasing labour force efficiency, and damaging infrastructure (Watts et al., 2019; Trancoso et al., 2020). Extreme heat resulted in a global economic loss of approximately USD 16 trillion from 1992 to 2013 (Callahan and Mankin, 2022). In China, the number of heat-related deaths quadrupled from 1900 to 2019 (Cai et al., 2020).

Case studies of past climate change and typical extreme events can provide insights for human society to better understand and respond to current climate change. However, there are few studies on extreme heat. In Europe, extreme heat in the past has been reconstructed and analysed in only a few studies or has been investigated at longer scales in conjunction with drought (Wetter et al., 2014; Orth et al., 2016; Camenisch et al., 2020). In China, reports of extreme heat are rarer than reports of other disasters, such as droughts, floods, and cold snaps. Research on extreme climate events over the last 2000 years in China indicates that there were 19 cases of abnormally hot summers across a large area of China (more than two to three provinces) over the past millennium (Zheng et al., 2014a). Compared with records of the 227 extreme droughts in northern China from 137 BCE–2000 CE and the 76 extreme cold winters in southern China from 1500–1950 CE, there are few records of heatwaves (Zheng et al., 2014a). The poor reporting of heatwaves is partly because they occur on shorter timescales and are therefore more difficult to recognize in longer time series (Tao et al., 2021). Droughts are usually recorded on seasonal to annual scales, whereas heatwaves have daily timescales (Deng et al., 2009). On the other hand, this may be because extreme heat is less devastating than droughts, floods, and cold events, which weaken food production systems, destroy homes, and even overthrow dynasties (Brázdil et al., 2019; Chen et al., 2021; Han and Yang, 2021; Xu et al., 2021).

Among the few instances of historical extreme-heat events, the 1743 event during the Qing dynasty (1644–1911 CE) is typical and has a relatively large number of records in historical documents. One previous study noted that the maximum daily temperature in Beijing on 25 July 1743 reached 44.4 °C (Zhang and Demaree, 2004). This value was obtained from early palace instruments and was measured by missionaries during the Qing dynasty (Zhang and Demaree, 2004). In the middle of the 18th century, western missionaries attempted to conduct meteorological observations in Chinese palaces (Udías, 1994; Domínguez-Castro, 2017). However, at that time, the measurement data were not yet fully available in Europe, and the observations in China were more discontinuous (Ren et al., 2022). The extreme-heat event of 1743 only lasted for a few days, which hinders our understanding of the entire process of heatwave development. It is also important to recognize the effects of extreme heat and its impact in regions by comparing this event with modern cases. Moreover, extreme heat occurred during the warmest period of the Little Ice Age in the 18th century, which was a stage of rapid climate warming (Ge et al., 2013; PAGES2k Consortium, 2019). An analysis of this case can provide new insights into our current situation in the face of more frequent heatwave events.

Factual records in historical documents are good resources for recovering extreme climate events from the past. The availability and effectiveness of historical documents as proxies for reconstructing past heatwave events are worth testing. China has a wide variety of historical documentary records, such as archives, local journals, and private diaries, which contain a large amount of meteorological, climatic, and disaster information (Ge et al., 2005, 2018; Chen et al., 2020). Methods such as regression analysis, physical modelling, grading, frequency statistics, and analogical analysis have been developed for the reconstruction of climate series based on historical documents (Zheng et al., 2014b). In reconstruction studies of extreme climate event cases, the inference of eigenvalues and the spatial and temporal statistics of key elements have also been used (Hao et al., 2010; Chen et al., 2020, 2021). However, these factors have more often been investigated in the reconstructions of droughts, storm floods, cold waves, and storm surges. There is a need to apply text-based analytical methods to the reconstruction of historical extreme-heat events. A more in-depth understanding of the extreme-heat case of 1743 and its impacts could be achieved through detailed analyses of historical documents.

The objective of this paper is to recover the processes and impacts of extreme heat in 1743 based on records from historical documents using textual-analysis methods. The core methodology used is textual analysis, including text-based grading and classification. The remainder of the paper is organized as follows. Section 2 describes the study area and methodology, focusing on how to extract temporal information about heat extremes, as well as on how to grade extreme-heat records and classify them by impact. Section 3 reveals the results of the development of extreme heat, the spatial pattern of extreme heat, and the characteristics of heat impacts. Finally, the strengths and limitations of the historical documents used to recover climate eigenvalues and societal impacts are discussed in Sect. 4.1. We also compare the 1743 extreme-heat event with modern cases to identify heatwave-prone areas and discuss the impact of heatwaves on the population in Sect. 4.2.

2 Materials and methods

2.1 Study area

According to historical records, the extreme heat of 1743 mainly occurred in northern China. The main provinces involved in the extreme heat were designated as the study area and included six provincial administrative units: Beijing, Tianjin, Hebei, Shanxi, Shandong, and Henan (Fig. 1). The study area is approximately located between 32–42° N and 110–125° E and is mainly situated on a lowland plain with an elevation level below 1000 m, including the North China Plain and the valley of Fenhe. Most of Shanxi and northern Hebei feature mountainous plateaus that are below 2000 m, such as the Taihang mountains, situated on the border between Hebei and Shanxi. The study area is dominated by a monsoon climate, characterized by rain and heat at the same time. The average daily maximum temperature in Beijing during July is 30.9 °C. In 1743, the year of the case, the old channel of the Yellow River was as shown in Fig. 1b. Three types of documents were used in the study, and their location attributes are labelled in Fig. 1. As mentioned in the Introduction, local annals contain very few records of extreme-heat events in the study area from the last 500 years, with 1743 being particularly prominent (Fig. 1c). The drought and flood index sequences in the study area are also shown for comparison to provide a temporal scenario for the study area, with

1743 being identified as a dry year in a relatively wet phase (Fig. 1c).

2.2 Data source

2.2.1 Historical documents used

In the recovery of extreme-heat information from 1743, we utilized three main types of documents: local annals; an official chronicle book; and archival materials represented by "memos to the emperor" (MEMOs for short), folded in accordion form. These three documents cover local and centralized perspectives, each of which has its own advantages.

1. *R1*. Local annals provide location information and can present the spatial distribution of extreme heat. They also recorded human feelings and impacts, reflecting the severity of the heat. The records of local annals were first extracted from *A Compendium of Chinese Meteorological Records of the Last 3000 Years* (Zhang, 2004). This is a classic compendium for the study of China's historical climate. It excerpts 7930 materials from local records, anthologies, and other sources. Meteorological records from the 13th century BCE to 1911 CE were chronologically compiled. The records related to the heat event of 1743 were mainly derived from various local annals. Traceability verification of each record was then performed by referring to local digital records collected by the National Library of China (http://read.nlc.cn/allSearch/searchList?searchType=12&showType=1&pageNo=1, last access: 2 November 2024).

2. *R2*. The *Factual Record of the Qing Dynasty* (Qing Shilu) is an official compiled chronicle from the Qing dynasty. It recorded the emperor's daily dealings and verbally released measures, and it includes descriptions of heat conditions in 1743 and measures to address them. The volume about Qing Shilu is large, but scholars have organized records related to climate, disasters, and impacts into a book. The book is named *A Compilation of Climate Impact Data from the Factual Record of the Qing Dynasty* and was published by the Institute of Natural Resources and Environment at the Chinese Academy of Sciences (IGSNRR, 2016). The heat-related records of 1743 presented in this study are from this book.

3. *R3*. MEMOs were letters from local officials to the emperor, used to periodically report on local conditions, including weather and disasters. They were widely used in the Qing dynasty. Today, most of them are housed in the First Historical Archives of China, and some are scattered across the National Library of China, Peking University, and the National Palace Museum in Taipei. The MEMOs used in our research are copied from the First Historical Archives of China[1].

The records of extreme heat were extracted via keywords. The records of extreme heat in historical documents mainly concern human perception, including terms such as "热" [hot], "暑" [hot], and "熏灼" [scorching]. In addition, there are many records describing people dying from heatstroke, and they usually include terms like "暍死" [death by heatstroke]. Using the keywords related to heat and human death from heatstroke mentioned above, extreme-heat records from historical documents were extracted. Notably, because a summer drought occurred at the same time in 1743 (Xiao et al., 2012), heat records are often accompanied by records of drought. However, separate drought records were not considered unless they indicated heat or that people died from heatstroke.

Finally, a total of 51 records of extreme heat were obtained from R1, covering five provincial-level administrative regions. Among these records, 1 was from Beijing, 4 were from Tianjin, 33 were from Hebei, 8 were from Shandong, and 5 were from Shanxi. In addition to documenting sensations of heat and instances of people dying from heatstroke, R1 also recorded other impacts of heat. Moreover, 10 extreme-heat records were obtained from R2, and two were obtained from R3 (Table 1). The records in R3 were obtained from the report of the governor of Zhili, whose residence was in Baoding, located in the province of Hebei (Fig. 1). Since R3 was submitted in stages, there are fewer records of heat.

All original textual material related to the 1743 extreme-heat event was digitized and organized in Table S1 in the Supplement. The records in R1 have spatial attributes that allow for the spatial presentation of information. The records in R2 and R3 have more specific time information because of their recording resolution, which extends down to the daily level, helping to provide some details about the process of the heatwave.

2.2.2 Other materials

To determine the precipitation conditions during the high-temperature period, Yu-Fen-Cun[2] data for June and July of 1743 from the study area were also obtained from the MEMOs of the First Historical Archives of China. Yu-Fen-Cun documented rain infiltration depth after rainfall events (Ge et al., 2005). We utilized this material to determine when large-scale precipitation occurred. The specific process is de-

[1] 9 Qinian Street, Dongcheng District, Beijing, China (https://fhac.com.cn/index.html, last access: 2 November 2024).

[2] Yu-Xue-Fen-Cun is a kind of agricultural weather record found in Qing dynasty archives, which documented the depth of infiltration after each precipitation event (Yu-Fen-Cun) and the snow depth (Xue-Fen-Cun). These records can be obtained from the First Historical Archives of China (see the detailed introduction in Ge et al., 2005).

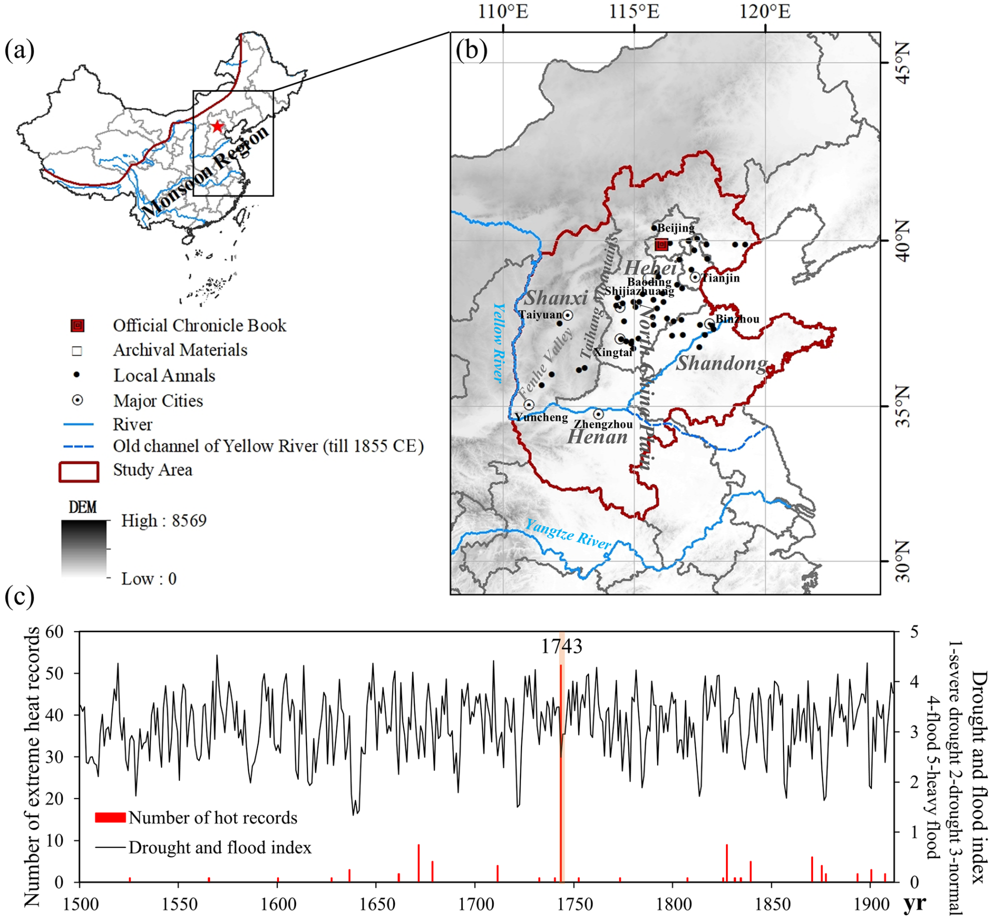

Figure 1. Study area and data distribution in this study. **(a)** Location of the study area in China. **(b)** Study area and data distribution. **(c)** Temporal scenarios of the number of heat records and drought and flood indices in the study area (1500–1911; Tao et al., 2021; Hao et al., 2022). DEM: digital elevation model.

scribed in Table S2. Early daily instrumental measurements from a study by Zhang and Demaree (2004) are also referenced by us.

2.3 Methods

Textual analysis was the main tool of the study. To restore a more complete picture of the extreme heat of 1743, we mainly needed the following information from the text: temporal information (dates), information on the severity of the heat, and the categories of heat impact.

2.3.1 Determination of dates

Historically, official and folk dates were recorded in various forms in China. Converting dates in the raw texts into a modern calendar format in a uniform manner is an important task when processing Chinese historical documents. The most common and easiest calendar to convert is the lunar calendar. In addition, there were also dates recorded according to festivals or solar terms. Examples of data conversion are shown below:

a. For dates recorded in the lunar calendar, a Chinese calendar spanning 2000 years (years 1–2060), abbreviated as Rf1 (WCWG, 1994), was utilized for direct conversion to Gregorian calendar dates. For example, the local annals of Rongcheng state that due to extreme heat and drought, many people died of heatstroke from the 24th day in the fifth lunar month to the 5th day in the sixth lunar month (row 21 of R1 in Table S1). By consulting Rf1, it is clear that the 24th day in the fifth lunar month was 15 July and that the 5th day in the sixth lunar month was 25 July.

b. When the date was recorded in terms of solar terms or festivals, it was determined according to general knowledge. For example, the MEMO from the governor of Zhili, Gao Bin, reports that following the first solar term in the sixth lunar month, the governor had felt very hot (row 1 of R3 in Table S1). In Chinese folklore, the first

Table 1. Historical documents used in the study of the 1743 extreme-heat event.

	Source types	Source	Site	Count	Examples
R1	Local annals	Annals of counties, prefectures, and states	51 counties or cities	51	In the fifth lunar month, there was severe drought and bitter heat. The soil and stone were scorched, and the metal on the roof melted. Many people died from the heat. (This note is from the local annals of Tianjin – row 2 of R1 in Table S1.) In the fifth lunar month, the hot wind seemed to be baking. Many people died from the heat. The wheat was withered, and the autumn grain could not be sown. (This note is from the local annals of Xianxian – row 27 of R1 in Table S1.)
R2	Official chronicle book	*Factual Record of the Qing Dynasty* (Qing Shilu)	Beijing	10	The emperor said it has been extremely hot lately in Beijing, and he was afraid that many people would suffer from heatstroke… (This note corresponds to Qing Shilu – row 4 of R2 in Table S1.)
R3	Archival materials	Memos to the emperor	Baoding, Hebei	2	Since half a month ago, it has been scorching, and the drought is worrying. There have been many people suffering from heatstroke on the road, and the people have been very afraid of death. (This note is a MEMO from Shen Qiyuan (Baoding) – row 2 of R3 in Table S1.)

solar term in the sixth lunar month refers to Minor Heat, which is around 8 July.

c. Some dates were described in the context of specific phases in a given month. The specific dates were then determined based on text details.

We focused on the following three types of dates. First, the dates marking the beginning or end of the heat event in the records indicate when heat was perceived and remembered. The second type consists of the dates of heat-related deaths as these are landmark events that reflect when heat became more severe. In addition, the records themselves have date attributes, such as the time of the signing of the MEMOS and the date when the emperor verbally released measures, which, together with the information provided in the content, offer information about the heat. At the same time, the act of the emperor verbally enacting measures against extreme heat also indicates that the heatwave had become more severe.

2.3.2 Grading the records by heat severity

Although there were a total of 51 records from R1, i.e. 51 locations where heatwaves were recorded, the differences in their textual descriptions of the events indicate differences in severity. To identify whether this difference represents a spatial inhomogeneity of extreme heat, we categorized the heatwave descriptions from the 51 sites into different degree classes based on certain principles. When grading by textual description, we considered two main aspects.

1. *Occurrence of heat-related deaths.* Heat that kills people is considered to be more severe than heat that does not kill people, and more deaths indicate more extreme heat.

2. *Use of words (semantic differences).* First, the adverbs of degree in the records made sense and could not be ignored. For example, descriptions such as "毒热" [toxically hot], "熏灼" [scorching], and "苦热" [bitterly hot] are believed to be more extreme than the ordinary "热" [hot] and "甚暑" [very hot]. Second, rich sentences with vivid metaphors and more text may indicate more severe heat. For example, the local annals of Anguo state, "五月大热，屋壁地榻什物尽如火炙，人多热死，连六七日." [It was particularly hot in the fifth lunar month. The walls, the floors, the beds, and all kinds of furnishings were as hot as fire. Many people died from the heat. This lasted for 6 to 7 d.] (This note is from row 23 of R1 in Table S1.) This record is very detailed and vivid, showing that the heat was even more extreme and impressive.

The heat records from R1 for 1743 were divided into four levels (Table 2). Level I indicates that people perceived unusual heat. Level II indicates that heat-related deaths occurred. In Level III, heat-related deaths were common, and in Level IV, heat was more intense and more impressive than in Level III. The number of records for each of the four levels was 4, 7, 22, and 18, respectively, which is somewhat consistent with a skewed distribution of extreme events.

Table 2. Criteria for grading heat event records from local annals (R1).

	Phenomenon	Example	Number
I	There are just normal and clear descriptions of heat.	In summer, it was very hot. (This note is from the local annals of Quwo – row 42 of R1 in Table S1.)	4
II	There are descriptions of heat and records of population deaths.	It was very hot in the last 10 d of the fifth lunar month, and there were people that died from the heat. (This note is from the local annals of Pingyuan – row 46 of R1 in Table S1.)	7
III	There are descriptions of heat and records of large numbers of population deaths, but the records are relatively brief.	In the sixth lunar month, there was drought and scorching heat, and many people died from the heat. (This note is from the local annals of Jize – row 34 of R1 in Table S1.)	22
IV	There are vivid descriptions of how hot it was and the large numbers of population deaths. The adjectives used to describe heat are rich, and the descriptions of deaths show that deaths in the population were very common.	It was particularly hot in the fifth lunar month. The walls, the floors, the beds, and all kinds of furnishings were as hot as fire. Many people died from the heat. This lasted for 6 to 7 d. (This note is from the local annals of Anguo – row 23 of R1 in Table S1.)	18

2.3.3 Classification of impact records

A total of 51 records from R1 documented the impacts of extreme heat and its timescale. Among these impacts, human heatstroke and death were the most common. We categorized the impacts of heat. Depending on the affected objects, the impacts of the 1743 extreme-heat event can be divided into four categories: (1) humans, who experienced heatstroke or died; (2) animals, which died or were physically impaired; (3) plants, which dried out or died from the heat; and (4) facilities, which were damaged by melting. In the second category, when crops were affected, they in turn affected harvests and food prices, leading to hunger. It should be emphasized that text was counted as belonging to the second category only if it clearly indicated that the crop was damaged by heat. However, crop failures are more likely to be caused by droughts or hot winds. It is thus difficult to identify how many were influenced by heat. We also discerned the timescales over which different impacts persisted. We then counted the number of impact records that still existed for each month on a monthly basis. For example, impact records of population deaths, damage to facilities, and animal injuries were counted for the month in which they were recorded; impact records of crop failures were counted for the month in which the crops were harvested; and economic and social impacts, on this basis, were counted for the month in which they were recorded. Table 3 shows examples of records and the number of records for each category of impact.

3 Results

3.1 Processes over time during the 1743 extreme-heat event

The calendar format was chosen to show the progression of extreme-heat events. The data obtained according to the details given in Sect. 2.3.1 are presented in the calendar (Fig. 2). There were nine records in R1, four in R2, and two in R3, indicating more specific periods of extreme heat according to the recording date, solar term, or phases of the month. Almost all of the records with specific end dates indicated that the heat lasted until 25 July, except for one R1 record that showed that it was particularly hot on 30 July. Regarding the beginning of the extreme heat, in R1, one record clearly indicated that it started on 15 July, two records indicated that it started on 17 July, and another record indicated that it started on 19 July. Furthermore, two records indicated that the heat began at the beginning of Sanfu[3] (19 July of that year), and another record indicated that the heat began at the end of the fifth lunar month (20 July is the last day of the fifth lunar month). For the records from R2, one indicated that heat began at the end of the fifth lunar month. Another record even indicated that the weather had been significantly hotter than in previous years since the summer solstice (22 June). For the records from R3, the situation of passers-by and farmers dying from the heat continued for at least a few days before 21 July, and following Minor Heat on 8 July, the weather had been extremely hot and hard to withstand. More detailed text about the timing of the extreme heat can be found in Table S3.

There were clear records of population deaths beginning on 14 or 15 July and continuing through at least the end of the heatwave on 25 July. R2 shows that on the 26th day of the fifth lunar month (17 July), Emperor Qianlong verbally deployed countermeasures with regard to the hot weather for the first time. From the 29th day of the fifth lunar month to the 5th day of the sixth lunar month (20 to 25 July), the em-

[3]Sanfu is part of the Chinese folk calendar. It refers to the hottest time of the year. It is divided into three periods, totalling 30 or 40 d, with 10 d in the first period, 10 or 20 d in the second period, and 10 d in the third period.

Table 3. Classification of the impacts of the 1743 heatwave and examples from local annals.

	First-order impact (number of records)	Second-order impact (number of records)	Examples	Timescale of the impact
1	Human (47)	–	In the sixth lunar month, there was no rain, and it was very hot. Many people died from the heat. In the early part of the sixth lunar month, the heat and drought were very severe, and the air felt hot, as if the woods were burning. In the early days of Sanfu, people died immediately after suffering heatstroke.	1 month
2	Animal (5)	–	It was very hot in the sixth lunar month; many people and livestock died from heatstroke. From spring to the sixth lunar month, there was no rain and a very hot summer. Chickens did not stay in their nests to incubate.	1 month
3	Plant (10)	Grain harvest (7) Grain price (3) Starvation (3)	There was a great drought. In the fifth to sixth lunar months, the hot wind felt inflammatory, as if it were burning. Many people died from the heat. The wheat was all withered, and the autumn grain could not be sown. The emperor issued an edict to feed the hungry from the eighth lunar month to the fifth lunar month of the next year. There was a vast area affected by severe drought. Indoor furnishings were hot. The wind was hot, as if it were burning, and many of the trees towards the southwest were dead. The harvests of both early and late rice were at 30 % and lacked flavour. Some of the rice grains were black. The grains of sorghum and yellow rice were not full, and the hot wind destroyed the bean seedlings. The price of grain rose to 150 wen per dou*. In the sixth lunar month, many people fled from the south of Tianjin and Wuding. Many passers-by died from the heat. There was contamination in the well, and the water was too shallow for the boat to operate.	Until the fifth lunar month of the next year
4	Facility (2)	–	In the fifth lunar month, there was severe drought and bitter heat. The soil and stone were scorched, and the metal on the roof melted. Many people died from the heat.	1 month

* Wen was a unit of currency in the Qing dynasty. Dou is a unit of weight. One dou is equivalent to 6.25 kg.

peror worried about hot weather almost every day. Yu-Fen-Cun also indicated almost no precipitation from 12 to 26 July.

Taking the above-mentioned information into consideration, we divided the development of extreme heat in 1743 into four stages, indicated by different shades of red (Fig. 2). Moreover, 22 June marked the earliest occurrence of heat in the record, after which the weather may have been on the hotter side. The second record indicated that on 8 July, significant heat appeared, and it is possible that the precipitation from the previous 2 d did not curb the momentum of the hotter weather. From 14 July onwards, heat-related deaths continued to be recorded. On 19 July and after this date, deaths continued, heat records increased significantly, and extreme heat began to be taken seriously by the central government.

3.2 Spatial pattern of heat severity in 1743

The map in Fig. 3 shows the spatial distribution of extreme-heat records and their different severity levels in R1. In 1743, extreme heat occurred mainly on the plains of the provinces of Hebei and Shandong, as well as in the valleys of southwestern Shanxi. Locations with more severe impacts and abundant records were mainly located on the pre-mountain plains east of the Taihang Mountains. For example, major cities in the eastern foothills of the Taihang Mountains, such as Beijing, Baoding, Shijiazhuang, and Xingtai, all recorded more severe heatwave events (Level IV). This may have been the consequence of a combination of weather and topographical factors. Level-I and Level-II records, with relatively mild impacts and abbreviated details, were mainly found on the fringes of the regions but were also distributed in the core areas. The record classes mentioned in the text reflect, to some

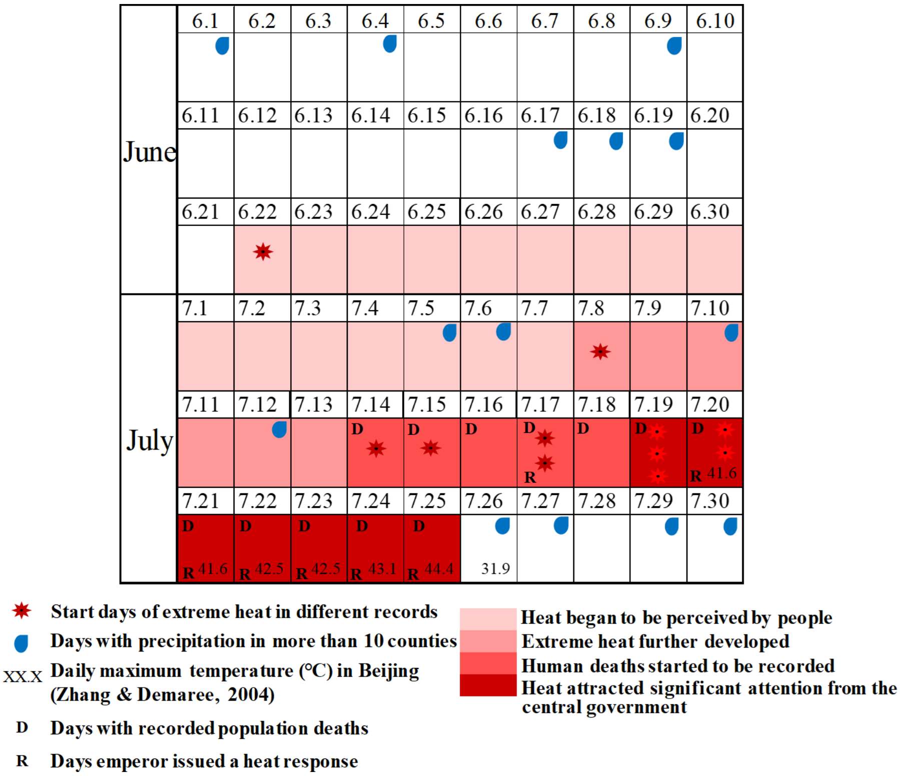

Figure 2. Processes over time during the 1743 extreme-heat event (presented in the form of a calendar).

extent, the distribution of the degree of heat, but they are also influenced by anthropogenic factors.

3.3 Impact of the 1743 extreme-heat event

The spatial distribution of the impact on humans is generally consistent with that of extreme heat. Of the 51 records from local annals, 47 involved human deaths. Although there were only five records of animal impacts and two of facility impacts, these were scattered throughout the study area (Fig. 4b and d). This suggests that these impacts may not have been isolated phenomena in 1743 but instead may have been omitted from the records because they were not emphasized. Moreover, 10 records on plant impacts were distributed in the eastern part of the province of Hebei and the northern part of the province of Shandong, which appears to be the result of compounding with drought or dry hot wind. Some records indicated that extreme heat caused crops to wither or soil moisture to deteriorate, resulting in crop failure or an inability to sow. These factors then affected regional food prices and resulted in famine and the migration of hungry people.

The subsequent effects of crop failure are also documented in the extreme-heat event of 1743. These effects led to higher grain prices, famine-related migration, and other social impacts. There were seven records from local annals documenting grain harvest failure due to hot weather. Five records reported reduced harvests of wheat (usually harvested in the fifth lunar month), and four reported reduced harvests of autumn grain (usually harvested in the ninth lunar month). Of the three records of increasing grain prices, two recorded an increase in annual grain prices, and one recorded an increase in grain prices due to autumn crop failure. There were four records in total mentioning people who starved. Among these, two indicated that relief measures for appeasing the starving lasted from the eight lunar month to the fifth lunar month of the next year, one indicated that starving people were exempted from taxes that year, and another directly stated that during the sixth to seventh lunar months, many starving people fled to other places. Together, the above-mentioned records suggest that the food security impacts of the 1743 heat event persisted for more than a year in the social system, lasting longer than the massive outbreaks of heat-related human deaths.

4 Discussion

4.1 What else can be learned from the textual records of the 1743 extreme-heat event?

In addition to the above information, which can be obtained more directly from the literature, we can further extract other information related to extreme heat from historical records through inference and generalization. However, confined to

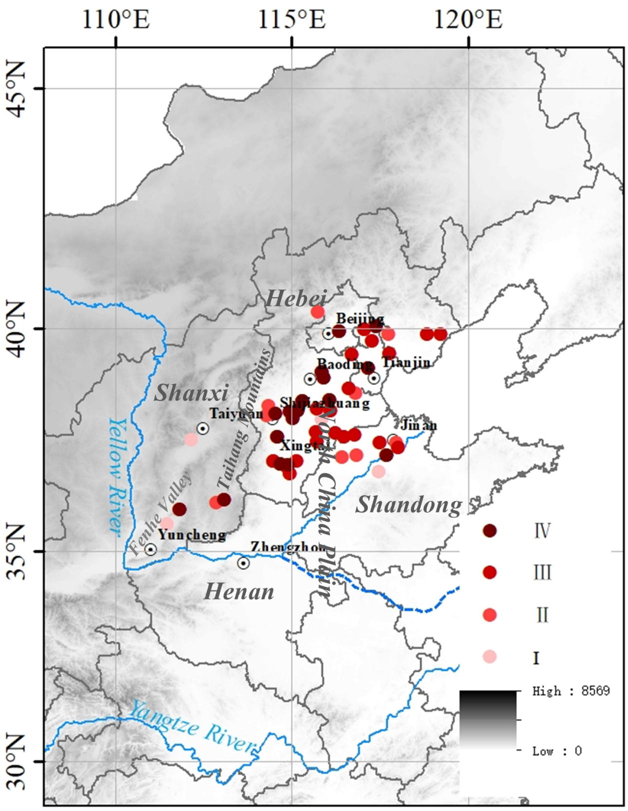

Figure 3. Spatial pattern of heat severity.

the characteristics of written records, we found that while some influence-related patterns can be observed, quantitative extrapolation of climate elements may be difficult.

4.1.1 Air temperature inference during the 1743 extreme-heat event

It is difficult to quantitatively reconstruct meteorological elements using qualitative historical documents. Quantitative inferences can be made by extrapolating from the present to the past; however, there is uncertainty.

In the reconstruction of extreme heat, we also attempted to infer the temperature range from the human body's heat perception and heatstroke response. There are several indices and models used to measure human perception and health risks under different environmental conditions in different countries or regions. We utilized NOAA's heat index and its danger warning classifications with respect to different air temperatures and relative humidities (Table 4). Based on the descriptions of massive heat-related deaths, it is clear that the Level-III and Level-IV counties (in Sect. 3.2) reached the warning level of "Extremely Hot". Using 40 %–50 % humidity, which is the multiyear average relative-humidity level for July in the study area, a range of possible temperatures were estimated. The calculations can be performed directly on the NOAA website (https://www.wpc.ncep.noaa.gov/html/heatindex.shtml, last access: 12 January 2024). The results indicated that a total of 40 counties corresponding to Levels III and IV were likely to have temperatures of 40 °C or higher during the 1743 extreme-heat event.

Although the estimated temperatures agree well with Zhang's results (Zhang, 2004), unlike physical, chemical, or biological proxies, textual records cannot help establish a quantitative equation with meteorological elements. Danger warning levels are artificially assigned classifications of general effects on people that do not correspond in a physical sense to individual responses.

4.1.2 Impact transmission chains during the 1743 extreme-heat event

Although the subjective nature of written documents limits their potential for quantitative reconstruction, this subjectivity also means that these documents focus on human experience and the impact of extreme weather and climate on human society. Thus, more details about human societies, such as the transmission of extreme-heat impacts, can be gleaned from historical documents.

Based on the records obtained in our research, it is possible to see the aspects affected by the extreme heat of 1743 and how they were transmitted and retained in human society. The results of Sect. 3.3 show that the main impact transmission chains were as follows: (1) heat leads to human death; (2) heat leads to animal physiological disorder or death; (3) heat (combined with drought or dry and hot wind) leads to crop damage, which leads to reduced food production, leading to hungry people and increased food prices; and (4) heat leads to facility damage. The third impact chain is special because it went beyond the physical effects of heat on living things or objects. The effects were magnified within society. It has been noted that the impact transmission chain of food security is the main way that extreme climate events have historically affected society (Fang et al., 2015). In ancient China, this was because food production was central to the livelihood of the people, and its impact could further influence higher levels of society. Indeed, because of the extra attention that it received, it occupies a large part of the record. The preference for recording socioeconomic impacts is consistent with the ancient Chinese concept of agriculture-based development.

4.2 Comparison with modern cases

Reconstructing past cases and comparing them with modern situations can provide more insights into extreme heat. Based on the results of this study, comparisons can be made in two directions. First, spatial comparisons can be used to determine whether areas that were hotter in 1743 behave the same way in modern times, and, second, we can explore responses to the effects of high-temperature heatwaves by comparing

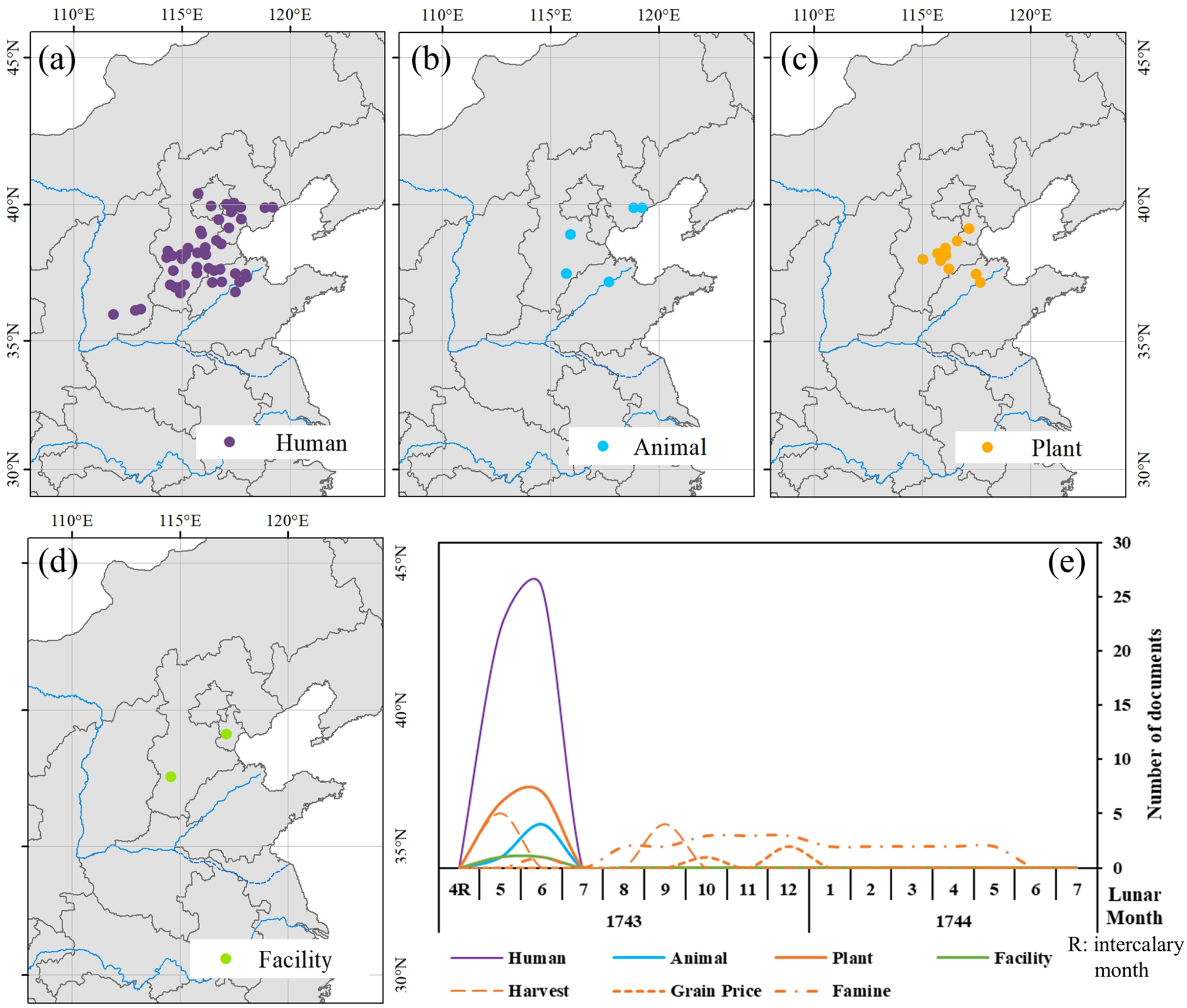

Figure 4. Spatial distributions and time series of records of extreme heat impact from 1743, classified by impact object (**(a)** humans, **(b)** animals, **(c)** plants, and **(d)** facilities; see Table 3). **(e)** Time series of impacts.

Table 4. Classifications of danger warnings for the heat index (NOAA; https://www.noaa.gov/sites/default/files/2022-05/heatindex_chart_rh.pdf, last access: 2 November 2024).

Classification	General effect on people	Estimated lower limit of temperature*
Very Warm	Fatigue possible with prolonged exposure and/or physical activity.	
Hot	Sunstroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity.	30–32 °C
Very Hot	Sunstroke, heat cramps, or heat exhaustion likely. Heatstroke possible with prolonged exposure and/or physical activity.	36–37 °C
Extremely Hot	Heatstroke and/or sunstroke highly likely with continued exposure.	40–43 °C

* Estimates were calculated at 40 %–50 % humidity.

the main effects of these heatwaves in terms of the number of population deaths.

4.2.1 Areas with more severe heat risk

With the increasing frequency of extreme heatwaves, areas suffering from particularly severe heat in different cases will be at greater risk in the future. According to the results in Sect. 3.2, severe heat was recorded in cities along the Taihang Mountains, such as Beijing, Tianjin, Baoding, and Shijiazhuang. It seems that, in recent years, these cities have also often been highlighted simultaneously during extreme-heat events in northern China.

To explore whether the extreme heat in northern China in 1743 is spatially consistent with that experienced in modern times, three typical years (2000, 2002, and 2022) were selected for comparison according to the results in Sect. 3.2. Daily maximum temperatures for summer (from June to August) recorded at 156 meteorological stations in the study area in 2000, 2002, and 2022 were obtained from the China Meteorological Data Service Center. We first defined the periods of extreme heat in 2000, 2000, and 2002. A heat event began when one or more stations recorded a maximum daily temperature higher than 38 °C and ended when no stations recorded a maximum daily temperature higher than 38 °C in the 5 d that followed. The results showed that in 2000, the heat period was long, lasting from the end of June to 26 July, and in 2002, it lasted from 10 to 19 July. In 2022, the heat event was at its earliest, occurring mainly in middle to late June (Fig. 5). Figure 5 shows the locations of the Level-IV records (from 1743) in which $T_{\max}$[4] exceeded 40 °C (in 2000, 2002, and 2022) during periods of extreme heat. Although extreme heat occurred at different times, the spatial characteristics of the $T_{\max}$ distribution were similar. The black boxes on the map indicate areas where severe heat occurred in all 4 years, mainly on the plains east of the Taihang Mountains. This region is a densely populated and economically significant area of the North China Plain, and the risk of urban heatwaves here is a concern for the future.

4.2.2 Population deaths due to extreme heat

Humans are the main victims of heatwave disasters. Population health and life safety are core concerns in extreme-heat disasters. Of all the effects of the extreme-heat event of 1743, human deaths were undoubtedly the most conspicuous and shocking. Descriptions of the people who died – such as those recounting that people died suddenly from heatstroke (rows 11–12 of R1 in Table S1) and that, when it was extremely hot, people died instantly on touching the burning air (row 6 of R1 in Table S1) – show that people suffered from severe heat sickness in 1743 under high temperatures. A letter from a French missionary, Antoine Gaubil, stated that between 14 and 25 July, 11 400 people in and around Beijing died due to heat (Zhang and Demaree, 2004). The spatial range in this investigation was undefined, but two records from local annals describe the number of deaths as dozens of people per day (rows 11–12 of R1 in Table S1). This indicates that the number of heat-related deaths in a single county was significant. Compared to modern extreme-heat cases, the scale of heat deaths in historical times was considerable (Table 5).

During the Qing dynasty, people in northern China mainly engaged in agriculture, which meant long hours of outdoor work, even in summer. Long-term exposure to high temperatures was the main cause of death. Even indoors, the threat of high temperatures was high due to a lack of cooling facilities. In the face of extreme heat, individuals and governments had very limited means of coping. Timely cooling and reducing the exposure of vulnerable populations were feasible approaches. There was a practice of storing ice in winter and using it in summer during the Qing dynasty. However, ice was a luxury item and available only in a few places for the elite. The records of giving ice soup and medicine, as well as those of setting up ice factories and distributing medicine for relief, only appeared in Beijing and Tianjin, while the rest of the county towns did not seem to have such conditions. Much-needed cooling measures following heatstroke were difficult to achieve. Measures such as building pergolas and ordering work to stop, recorded in the *Factual Record of the Qing Dynasty*, were used to reduce the exposure of special groups.

Although the number of deaths has decreased compared to that in ancient times, the threat of heat to human health is still serious in modern times. Studies have shown that the risk of death in a population increases rapidly and nonlinearly at high temperatures (Gasparrini et al., 2015). The excess mortality of people with cardiovascular and respiratory diseases due to high temperatures is very significant (Cheng et al., 2019). Once a person experiences heat apoplexy, the risk of death is very high. In 2022, many parts of the Northern Hemisphere experienced extreme heat. In the absence of air conditioning, many Europeans sought shade, fountains, or pools to cool off provisionally. Most of the time, people are helpless in the face of extreme heat. Reducing going out and paying attention to people who work outdoors, as well as those who have underlying diseases, are limited but necessary measures for addressing extreme heat.

4.3 How the rest of the Northern Hemisphere behaved during the summer of 1743

In this section, we discuss whether the extreme heat of 1743 experienced in northern China was remotely related to that experienced in other regions by comparing proxy data from multiple regions and explore whether these regions shared similar climatic mechanisms or contexts with those of modern heat events. Modern studies on heatwave mechanisms

[4] $T_{\max}$ refers to the maximum value of the daily maximum temperature in the current month.

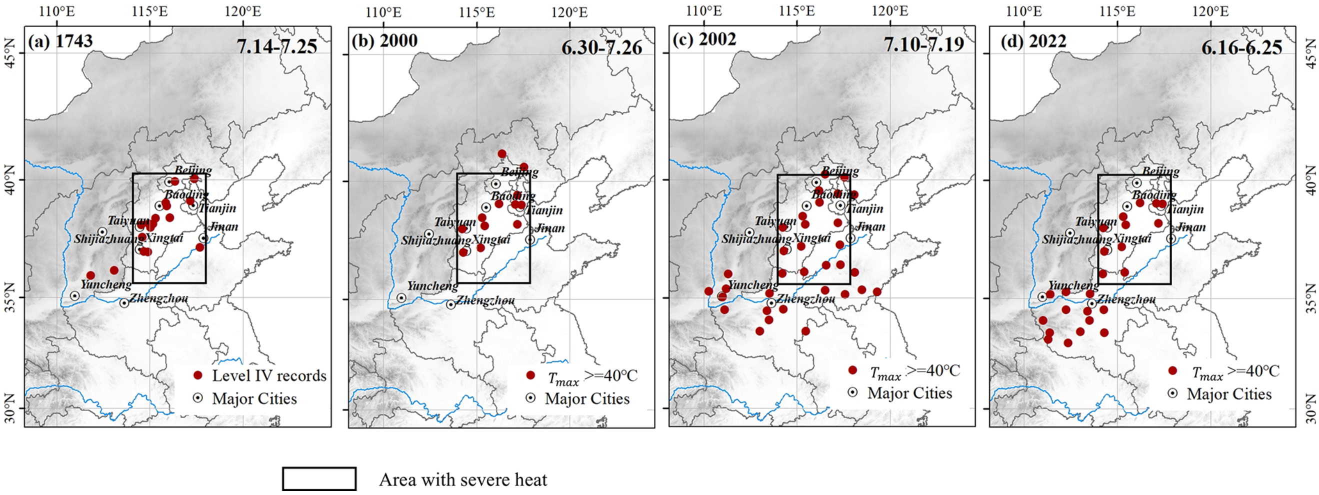

Figure 5. Spatial distributions and time series of extreme-heat impacts in 1743.

Table 5. A comparison of the mortality from the 1743 heat event with that of typical modern heatwaves.

Year	Region	Days when daily maximum temperature was above 35 °C	Number of heat-related deaths
1743	Northern China	At least ∼ 12 d (7.14–7.25)	11 400 in Beijing and the surrounding areas
2003	France	15 d (8.4–8.18)	3548 (Alain et al., 2006)
2013	Shanghai, China	33 d (7.2–7.4, 7.8–7.11, 7.12–7.31, and 8.3–8.12)	167 (Sun et al., 2014)
2017	England	10 d (6.17–6.23 and 7.5–7.7)	1489 (Rustemeyer and Howells, 2021)

have revealed that extreme-heat events in northern China, North America, and Europe are often synchronized. The reason behind this is that westerly wind belt fluctuations in the Northern Hemisphere generate multiple low and high cutoff pressures, and high-pressure ridges often form on continents, thus causing synchronized high temperatures across different continents. For example, in the summer of 2022, very intense and extreme heat occurred simultaneously in northern China and Europe. These studies have also indicated that global warming has caused the westerly wind belt to move northwards and become narrower, and it is more likely that multiple high-pressure ridges form across continents, which may be the cause of the current high-temperature extremes in the Northern Hemisphere (Deng et al., 2018; Kornhuber et al., 2019, 2020; Yang et al., 2021).

Although higher-resolution heatwave records are relatively difficult to obtain, it is possible to capture information about the 1743 summer event from long time series. We collected 17 palaeoclimatic reconstruction series for the Northern Hemisphere from NOAA (https://www.ncei.noaa.gov/access/paleo-search, last access: 2 November 2024). There were five series from Asia, six from Europe, and six from North America. The reconstructed indices of these studies were the temperatures for partial months of the warm season (March–September), summer (June–August), or partial months of summer. For 1743, the degree of warmth/cooling and the trend of warmth/cooling in the series were investigated. Firstly, the degree of warmth/cooling in 1743 was expressed by a grade. We divided the reconstructed values of a series covering the entire Little Ice Age into four grades based on quartiles. The Little Ice Age has been defined by *Encyclopædia Britannica* as occurring from 1301–1850. If the reconstructed sequence was shorter than this period, the calculation was based on the actual start and end times of the series. Secondly, the warm/cold trend was calculated using an 11-year trend (extending before and after 1743).

The map in Fig. 6 displays the degrees of warmth and cooling, as well as the trend of the 1743 summer event, across different reconstructed sequences in the Northern Hemisphere. The colours of the circles indicate warm summers in northeastern Asia and North America, whereas they show that Europe was uniformly cold, which may have been influenced by extreme cold spring events in Europe in the 1740s (Brázdil et al., 2018; Brönnimann and Brugnara, 2023). The decadal trend in most places was warming, which is consistent with the integration of cold and warm reconstructions in the Northern Hemisphere over the past millennium (PAGES2k Consortium, 2017). The temperature increased in 1743, which was during the Little Ice Age. More climatic records from eastern Asia also support this phenomenon. For example, climatic records from both Japan and Beijing indicate that the 1740s marked the beginning of the warm period (Aono and Kazui, 2008; Liu and Fang, 2017; Aono and Nishitani, 2022).

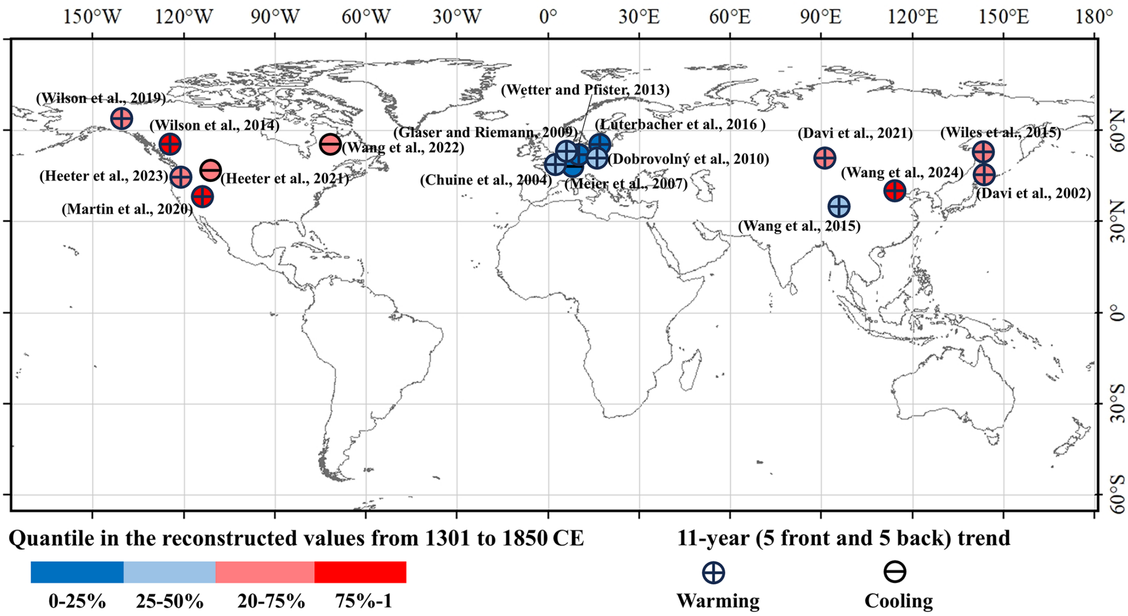

Figure 6. Behaviour in the rest of the Northern Hemisphere during the summer of 1743. Publisher's remark: please note that the above figure contains disputed territories.

However, it is difficult to determine whether short-term heatwaves occurred in Europe and North America due to the lack of simultaneous high-resolution textual or instrumental records in other regions. It is also unclear whether the fluctuations in the westerlies had a chain response at the middle and high latitudes of the Northern Hemisphere. Therefore, we believe that the 1743 heat event may have only been very extreme on a regional scale during a relatively warm period. This is unlike the large-scale extreme-heat events and heatwaves in the Northern Hemisphere caused by global warming in recent years.

5 Conclusion

In this research, we utilized three kinds of historical materials (local annals, archives, and official history books), using methods of textual analysis, grading, and classification to investigate the temporal development, spatial patterns, and characteristics of the impacts of extreme heat during 1743. We further inferred the range of extreme temperatures based on textual information and analysed the chain of impact transmission. The spatial characteristics of extreme heat and the number of deaths caused were compared with such aspects in typical modern examples. We also examined climate performance in other regions of the Northern Hemisphere in 1743.

The results showed that most of the Northern Hemisphere experienced an interdecadal temperature increase during the summer of 1743, with eastern Asia and North America on the warmer side. The extreme heat of 1743 experienced in northern China occurred against this climate background, as detailed below:

1. The extreme heat of 1743 gradually increased. On 22 June, people became aware of the unusual heat. After 8 July, the heat continued to develop. Beginning on 14 July, human deaths caused by the heatwave began to be recorded, and beginning on 19 July, the severe effects of the heatwave were given high priority by the central government. The heat peaked on 25 July and was later relieved by precipitation. The maximum daily temperature in 40 counties likely reached 40–43 °C.

2. The extreme-heat events of 1743 occurred on the plains of the provinces of Hebei and Shandong and in the valleys of southwestern Shanxi. The worst heat was concentrated on the plains east of the Taihang Mountains, with the areas around Baoding, Shijiazhuang, and Xingtai being the main regions affected. These areas are also at high risk for heatwaves on the North China Plain in modern times.

3. The extreme-heat event of 1743 caused damage to human health, plants, animals, and facilities. The impacts on crops persisted in human social systems. The number of deaths from extreme heatwaves has decreased compared to historical period, but population deaths remain the most significant impact of extreme-heat events. Timely cooling and reducing exposure have been limited but necessary means of addressing high temperatures in both ancient and modern times.

Data availability. All original textual records in this study have been digitized and organized in Table S1.

Supplement. The supplement related to this article is available online at: https://doi.org/10.5194/cp-20-2455-2024-supplement.

Author contributions. LT and YS contributed to the study's conception and design. Funding acquisition was handled by YS. All historical documents were acquired, digitized, and processed by LT and mapped by LT, XC, and FT. XC provided the writing outline, and FT contributed ideas to the discussion. The first draft of the paper was written by LT, and all authors commented on previous versions of the paper. All authors read and approved the final paper.

Competing interests. The contact author has declared that none of the authors has any competing interests.

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Acknowledgements. We would like to thank all colleagues in our research group for providing valuable discussions and suggestions. We would like to thank the reviewers and editors for their valuable comments.

Financial support. This research has been supported by the Major Program of the National Fund of Philosophy and Social Science of China (grant no. 22&ZD223).

Review statement. This paper was edited by Chantal Camenisch and reviewed by two anonymous referees.

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