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Process, spatial pattern and impacts of 1743 Extreme heat: From the perspective of historical documents

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Abstract. The study of historical extreme heat is helpful to understand modern heat waves. By collecting 63 historical documents from 3 kinds of historical materials and using methods of text analysis methods based on keywords, grading and classification, this research recovered and analyzed the process over time, the spatial pattern of the heat severity and the extreme heat impact of the North China extreme heat in 1743. The results show: 1) The extreme heat of 1743 began to noticed by people on June 22, began to kill people on July 14, and was most severe and attracted great attention from the central government between July 14 and 25. 2) The extreme heat occurred in the plains north of the Yellow River and in the valleys of southwestern Shanxi. Areas in the plains east of the Taihang Mountains such as Baoding, Shijiazhuang, and Xingtai suffered worst heat. They are also at high risk for heat waves in the North China Plain in modern times. 3) In 1743, the heat affected people, animals, plants and facilities, with the most severe impact of human deaths. The death toll in a single county reached dozens in a single day. Timely cooling and reducing exposure are limited but necessary means to deal with high temperatures in both ancient and modern times.

1 Introduction

Extreme heat and heat waves are becoming more severe and frequent in the context of global warming, which also heightens our curiosity about extreme heat events in the past. The IPCC's Sixth Climate Assessment Report concludes that as anthropogenic global warming deepens, there is a high probability that the intensity and frequency of extreme weather events will continue to become more extreme(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 poses threats to human life and socioeconomics(Cai et al., 2020;Callahan and Mankin, 2022). It therefore deserves more attention and research. However, the history of modern instrumental measurement data is just over a hundred years old. Case studies on past climate change and impacts can add the understanding of climate mechanism and provide inspiration to better understand and cope with current climate change (IPCC, 2013;Wetter and Pfister, 2013;Cai et al., 2020;Zhou et al., 2021).

Unluckily, few research focus on extreme heat of the past compared to other types of extreme events such as droughts, rain-floods and cold event. In Europe, extreme heat of the past has been reconstructed and analyzed in only a few studies, or

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discussed on 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 similarly rare compared to disasters such as droughts, floods and cold snaps. The research of extreme weather events in the last 2000 years in China shows that there were 19 cases of abnormally hot summer in a large area (more than 2 to 3 provinces) of China in the past millennium (Zheng et al., 2014b). Compared with 227 extreme droughts in North China during 137BC-2000 and 76 extreme cold winters in South China during 1500-1950, there are few records(Zheng et al., 2014b). The result that heatwaves are so poorly reported is partly due to the fact that they occur on shorter time scales and are therefore more difficult to recognize in long time series(Tao et al., 2021). Droughts are usually recorded on seasonal to annual scales, whereas heat waves have daily time scales(Deng et al., 2009). On the other hand, this may be because extreme heat is less devastating than droughts, floods and cold, which bring down 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).

Factual records in the historical documents are good media to learn the law of extreme climate events. China has a wide variety of historical documentary records, which contain a large amount of meteorological, climatic and disaster information(Ge et al., 2005;Ge et al., 2018;Chen et al., 2020). Methods such as regression analysis, physical modeling, grading, frequency statistics, analogical analysis, etc., have been developed in the reconstruction of climate series based on historical documents(Zheng et al., 2014a). In the reconstruction study of extreme climate events, these methods have also been used for reconstruction of eigenvalues and spatial and temporal statistics of key elements(Hao et al., 2010;Chen et al., 2020;Chen et al., 2021). But they are also more often used in the reconstruction of droughts, storm floods, cold waves, and storm surges. The effectiveness of historical documents as proxies in reconstructing past heat wave events is worth testing.

The year 1743 is one of the few recorded historical examples of a typical heat wave, and the knowledge of this case and impacts could be more detailed and deepen by referring to historical documents. One previous study pointed out that the maximum daily temperature in Beijing on 25th July had reached 44.4°C(Zhang and Demaree, 2004). This value was from the early palace instruments and measured by missionaries in the Qing Dynasty (Zhang and Demaree, 2004). Sporadic records of observations in 18th-century China come from foreign missionaries (Udías, 1994;Domínguez-Castro, 2017). At that time, the measurement data were not yet fully available in Europe, and the observations in China were also discontinuous (Ren et al., 2022). The extreme heat record in 1743 was only a few short days, which hindered our knowing of the entire process of heat wave development. It's also important to recognize the performance of extreme heat and its impact in regions other than Beijing. What's more, the extreme heat occurred in the warmest period of the Little Ice Age in the 18th century, and was in the stage of rapid climate warming (Ge et al., 2013;Neukom et al., 2019). The analysis of this case can provide new insights into our current situation in the face of more frequent heatwave events.

The objective of this paper is to recover the process and impact of extreme heat in 1743 based on records in historical documents. The core methodology used is textual analysis, including text-based grading and classification, etc. The rest of the paper is organized as follows: Section 2 describes the study area and methodology, which focuses on how to extract temporal information of heat extremes, as well as to grade extreme heat records, and classify them by impact. Section 3 shows the results of the extreme heat development, spatial pattern of extreme heat and characteristics of heat impacts. Finally,

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the strengths and limitations of historical documents in recovering climate eigenvalues and societal impacts are discussed in 4.1. We also compared 1743 extreme heat with modern cases to identify the heatwave prone areas and discussed the heatwave impact on population.

2. Materials and Methods

2.1 Study area

According to historical records, the extreme heat in 1743 mainly occurred in North China. The main provinces involved in extreme heat were designated as study area, including six provincial administrative units of Beijing, Tianjin, Hebei, Shanxi, Shandong and Henan (Fig.1). The study area is roughly located between 32-42°N and 110-125°E, mainly in lowland plain, with an elevation below 200 m. Most of Shanxi and northern Hebei have some mountainous plateaus, which are below 2000 m. The study area is dominated by monsoon climate with rain and heat at the same time. The annual average daily maximum temperature in Beijing in July is 30.9°C.

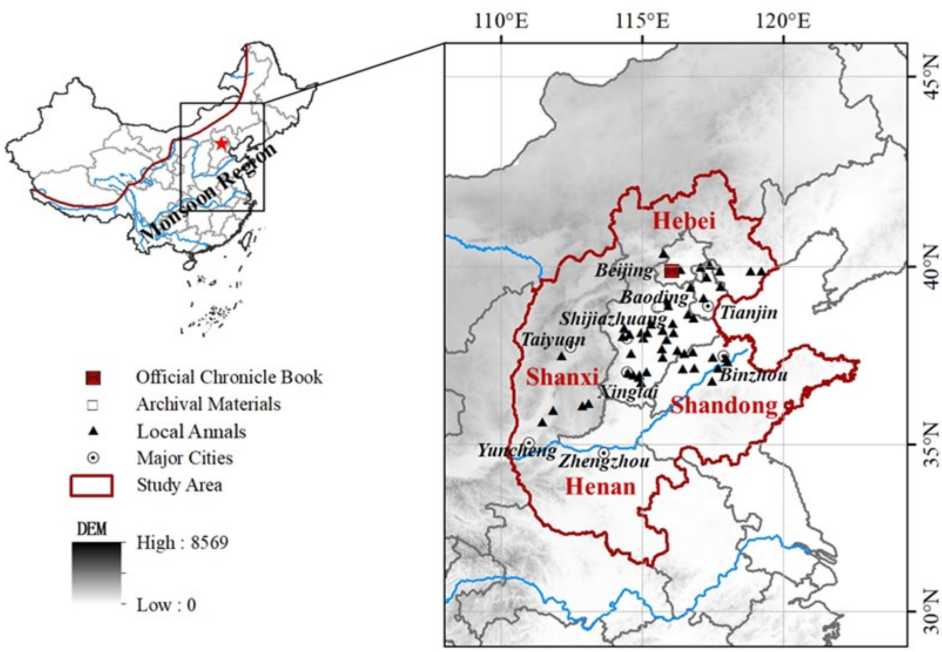

Figure 1: Study area and data distribution in this study.

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2.2 Data source

2.2.1 Historical Documents used

In the recovery of the extreme heat in 1743, we mainly refer to three types of documents. They are Local Annals, official Chronicle book and the archival materials represented by Memos to the Emperor folded in accordion form (MEMOs for short). Each of them has its own advantages.

(1) **R1**. Local annals have location information and can present the spatial distribution of extreme heat. They also recorded the feelings and impact of human, reflecting the intensity of the heat. The records of local annals were first extracted from the book named A Collection of Meteorological Records of the Last 3,000 years in China (Zhang 2004). This is a c lassic compendium in the study of China's historical climate. It excerpts 7,930 materials from local records, anthologies, and other sources. Meteorological records from the 13th century B.C. to 1911 A.D. were chronologically compiled. Records relating to the heat event of 1743 are just mainly derived from various local annals. Then, traceability verification of each record was done referring to the digital local records collected by the National Library of China[1].

(2) **R2**. Factual Record of Qing Dynasty (Qing Shilu) is the official compiled chronicle book in Qing Dynasty. It recorded the emperor's daily dealings and measures released verbally, in which heat condition and measures to deal with them in 1743 can be found. The volume of the Qing Shilu is huge, but scholars have already organized the records related to climate, disasters and impacts into a book. The book is named A Compilation of Climate Impact data form Factual Record of Qing Dynasty, published by the Institute of Natural Resources and Environment of the Chinese Academy of Sciences (CAS 2016). The heat-related records of 1743 in this study comes just from this book.

(3) **R3**. MEMOs were letters from local officials to the emperor to periodically report local conditions, including weather and disasters. They were widely used in the Qing Dynasty to inform the emperor of local weather and disasters. Today, most of them are housed in the First Archives of Chinese History, and some are scattered in the National Library of China, Peking University, and the National Palace Museum in Taipei. MEMOs in our research are copied from the First Historical Archives of China[2].

Records about extreme heat were extracted by keyword. The records of extreme heat in historical documents are mainly about human perception, such as 热(hot), 暑(hot) and 熏灼(scorching). In addition, there were many records of people dying from heat stroke, and they are usually recorded as 暍死 (die of heatstroke). Using these keywords of heat and human death from heat stroke mentioned above, extreme heat records from historical documents were extracted. It should be noted that due to the summer drought occurred the same time in 1743(Xiao et al. 2012), the records of heat often accompanied by drought. However, separate drought records were not considered as long as they did not indicate heat or that people died of heatstroke.

[1] *http://read.nlc.cn/allSearch/searchList?searchType=12&showType=1&pageNo=1*

[2] No. 9, Qinian Street, Dongcheng District, Beijing, China (*https://fhac.com.cn/index.html*)

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Finally, a total of 51 records of extreme heat were obtained from R1, covering five provincial-level administrative regions. Among them, 1 was in Beijing, 4 in Tianjin, 33 in Hebei, 8 in Shandong and 5 in Shanxi. In addition to recording the sensation of heat and the phenomenon of people dying of heat stroke, local annals also record some other impacts of heat. There were 10 and 2 extreme heat records were obtained from the R2 and R3 (Tab.1). Records in R3 were from the governor of Zhili (Hebei province in history), whose residence was Baoding, Hebei Province (Fig.1).

Table 1: Historical Documents used in the recovery of the 1743 extreme heat

	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 is severe drought and* ***bitterly heat****. The soil and stone were scorched, and the metal on the roof melted. Many people died of heat. ——Local annal of Tianjin*(Supplement1-R1-2) *In the fifth lunar month, the* ***hot wind seemed to be baking****.* ***Many people died of heat****. The wheat was withered and the autumn grain could not be sown. ——Local annal of Xianxian* (Supplement1-R1-27)
R2	**Official Chronicle book**	*Factual Record of Qing Dynasty (Qing Shiru)*	Beijing	10	*The emperor said it is extremely hot lately in Beijing and he was afraid that there would be many people get heat stroke……—— Qing Shiru* (Supplement1-R2-4)
R3	**Archival materials**	Memos to the Emperor	Baoding, Hebei	2	*Since the half month ago,* ***it had been scorching*** *and the drought is worrying. There were* ***many people suffering from heatstroke on the road****, and the people were very afraid of death. ——MEMO from Shen Qiyuan in Baoding* (Supplement1-R3-2)

All original textual material relating to the 1743 extreme heat has been digitized and organized in Supplement 1. The records in R1 have spatial attributes that allow for spatial presentation of information. Records in R2 and R3 have more specific time information because of their recording resolution down to the daily level, which can help obtaining some details of the development of heat wave.

2.2.2 Other Materials

To obtain precipitation conditions during the high temperature period, Yu-Fen-Cun in June and July of 1743 in study area were also copied from the MEMOs of the First Historical Archives of China. Yu-Fen-Cun documented the rain infiltration depth after a rain fall(Ge et al., 2005).. We referred to this material to determine when large scale of precipitation occurred. See Supplement 2 for the specific process. The early daily instrumental measurements in Zhang and Demaree's study are referenced by us.

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2.3 Methods

Textual analysis is the main tool of the study. In order to restore a more complete picture of the extreme heat of 1743, we mainly needed the following information from the text. They are temporal information, mainly date information; information on the severity; and categories of impact.

2.3.1 Determination of Dates

In historical period China, official and folk dates were recorded in various form. Converting the dates in the data sources to a uniform manner in modern calendar is an important task when processing Chinese historical documents. Among them, the most common and easy to convert is the lunar calendar. In addition, there are also dates recorded according to festivals or solar terms. Examples of date conversion are shown below:

a) For those recorded in the lunar calendar, refer to the Chinese Calendar for Two Thousand Years: 1-2060"(abbreviated as Rf1) for direct conversion to Gregorian calendar dates. For example, the local annal of Rongcheng said: "due to the extreme heat and drought, many people died of heat stroke from the 24th day in 5th lunar month to 5th in 6th lunar month." (Supplement1-R1-21) By consulting Rf1 it is clear that the 24th day in 5th lunar month was July 15, and the 5th day in 6th lunar month was July 25.

b) Where time is recorded in terms of the solar terms or festival, the date is determined according to general knowledge. For example, the MEMO from Zhili Governor Gao Bin reported: "Since the first solar term in the 6th lunar month, I feel very hot." (Supplement1-R3-2). In Chinese folklore, the first solar term in the 6th lunar month refers to Minor Heat, on around July 8.

c) Some are described as specific phases in a given month. Their dates were determine based on text details.

We focus on the following three types of dates. First, the dates of the beginning or end of heat in the records; they reflect when heat was perceived and remembered. The second are the dates of heat-related deaths, as this is a landmark event that reflecting a new stage of the heat development. In addition, the records themselves have date attributes, such as the time of signing of the MEMOS and the date when the emperor verbally released measures, which together with the information in content to provide time clue of heat. At the same time, the very act of the emperor verbally enacting measures against extreme heat also reflected the heatwave became more severe.

2.3.2 Grading the records by heat Severity

Although there are a total of 51 heatwave records from R1, i.e. 51 locations where heatwaves were recorded, the differences in their textual descriptions of the events indicate differences in severity. In order to identify whether this difference represents a spatial inhomogeneity of the extreme heat, we categorized the heat wave descriptions at the 51 sites into different degree classes according to certain principles. When grading by textual description, we mainly considered two aspects. They are, respectively, the recorded facts of impact and the use of words

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(1) **Whether there were heat-related deaths.** Heat that kills people is more severe than heat that does not kill people, and more deaths indicate more extreme heat event.

(2) **The use of words (semantic difference)**. First, it made sense to use adverbs of degree. For example, the descriptions such as “**毒热 (toxically hot)**”, “**熏灼 (scorching)”** and “**苦热 (bitterly hot)**” are believed to be more extreme than those of ordinary “**热 (hot)**” and “**甚暑 (very hot)**”. Second, rich sentences with vivid metaphors and more text may point to more severe heat. For example, the local Annal of Anguo said: “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, floors, beds and all kinds of furnishings were as hot as fire. Many people died from the heat. This lasted for six to seven days)” (Supplement1-R1-23) This record is very detailed and vivid, showing that the heat is even more extreme and impressive.

The 1743 heat records from R1 were divided into 4 levels (Tab.2). Among them, grade I indicates that one perceived unusual heat. Level II indicates that Heat-related deaths occurred. Level III indicates that heat-related deaths were common and Level 4 compared to level 3 suggests that heat is rarer and more impressive. The amount of the records for each of the four levels are 4, 7, 22 and 18, which is somewhat consistent with a skewed distribution of extreme events.

Table 2: Criteria for grading heat event records from Local Annals (R2)

	Phenomenon	Example	Amount
I	There are just normal and clear descriptions about hot.	*In summer, it was very hot. ——Local annal of Quwo (Supplement1-R1-42)*	**4**
II	There are descriptions of heat and records of population deaths.	*It was great hot in the last ten days of the 5th lunar month, there were people died from heat. ——Local annal of Quwo (Supplement1-R1-46)*	**7**
III	There are descriptions of heat and records of large population deaths, but the records are relatively brief.	*In the sixth lunar month there was drought and scorching heat, and many people died from heat. ——Local annal of Quzhou (Supplement1-R1-34)*	**22**
IV	There are vivid descriptions about how hot was and there were large number of population deaths. The adjectives to describe heat are rich and description about death show that the phenomenon of population death is very common.	*It was particularly hot in the fifth lunar month. The walls, floors, beds and all kinds of furnishings were as hot as fire. Many people died from the heat. This lasted for six to seven days. ——Local annal of Anguo (Supplement1-R1-23)*	**18**

2.3.3 Classification of impact records

A number of the 51 records from R1 documented the impacts of the extreme heat and their timescale. Among them, human heat stroke and death are the major aspects. We categorized and statistically analyzed the impacts of the heat. Depending on affected objects, the impacts of the 1743 extreme heat can be divided into four categories, they are (1) Human, who got heat stroke or died; (2) Animals, those were dead or physically impaired; (3) Plants, which were dried out or died from heat; (4) Facilities, those were damaged by melting. In category (2), when crops are affected, they in turn affects harvests, food prices and leads to hunger. The number of such records has also been further counted. We also discerned the time scales over which different impacts persist. Tab.3 shows examples of records and the number of records for each category of impact.

Table 3: Classification of the impacts of the 1743 heat wave and examples in Local Annals

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	1st order impact (Number of records)	2nd order impact (Number of records)	Examples	Timescale of impact
1	**Human（47）**		*In the 6th lunar month, no rain, very hot,* ***many people died of heat.*** *In early of the 6th lunar month, the heat and drought were very severe, and the air touched hot as if woods were burning. In the early days of Sanfu,* ***people died immediately after heat stroke.***	In 1 month
2	**Animal（5）**	-	*It's very hot in 6th lunar month, many people and* ***live stocks died of heatstroke****.* *From spring to the 6th lunar month there was no rain, very hot summer,* ***chickens didn't stay in their nests and incubate.***	In 1 month
3	**Plant（10）**	Grain Harvest（7） Grain Price（3） Starvation（3）	*Great drought. In the 5-6th lunar month, hot wind was inflammatory as if burning. Many people died of heat. The* ***wheat was all withered*** *and the* ***autumn grain could not be sown****. The emperor issued an edict to feed* ***the hungry*** *form the* ***8th lunar month to the 5th lunar month of next year****.* *A thousand miles of drought. Indoor furnishings were hot. The wind was hot like burning, and many of the* ***trees toward the southwest were dead****.* ***The harvests of both early and late rice were 30%, and lack of flavor****.* ***Part of rice grains are black.*** *The grains of sorghum and yellow rice were not full and the hot wind destroyed the bean seedlings.* ***The price of grain went up to 150 wen per dou****. In the 6th lunar month,* ***many people fled from South of Tianjin and Wuding****. Many passers-by died of heat. There was contamination in the well and the water was too shallow for the boat to run.*	to the 5th lunar month of 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 of heat.*	In 1 month

3. Results

3.1 Process over time of 1743 extreme heat

The format of calendar was chosen to show the progression of extreme heat events. The date information obtained according to 2.3.1 is presented in the calendar. (Fig.2). There are 9 records in R1, 4 in R2 and 2 in R3 pointed out more specific periods of extreme heat by recoding date, solar term, or phases in the month. Almost all of records with specific end date indicate that the heat lasted until July 25, except for one R1 record that was particularly hot on July 30, which is considered an outlier. As for the beginning of the extreme heat in R1, one record clearly indicates that it started on July 15, 2 records start on July 17, 1 record starts on July 19, 2 records show that the heat began on the beginning of Sanfu [3](July 19 of the year), and another record shows that the heat began at the end of the 5th lunar month (July 20 is the last day of the 5th lunar month). In R2, 1 record showed that the heat began at the end of the 5th lunar month. Another record even shows that the weather has been significantly hotter than in previous years since the Summer Solstice (June 22). In R3, the situation of passers-by and farmers dying of heat had continued for at least a few days until July 21, and since Minor Heat, July 8, the weather has been extremely hot and hard to stand. A more detailed text about the timing of the extreme heat can be seen in the table in Supplement2.

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

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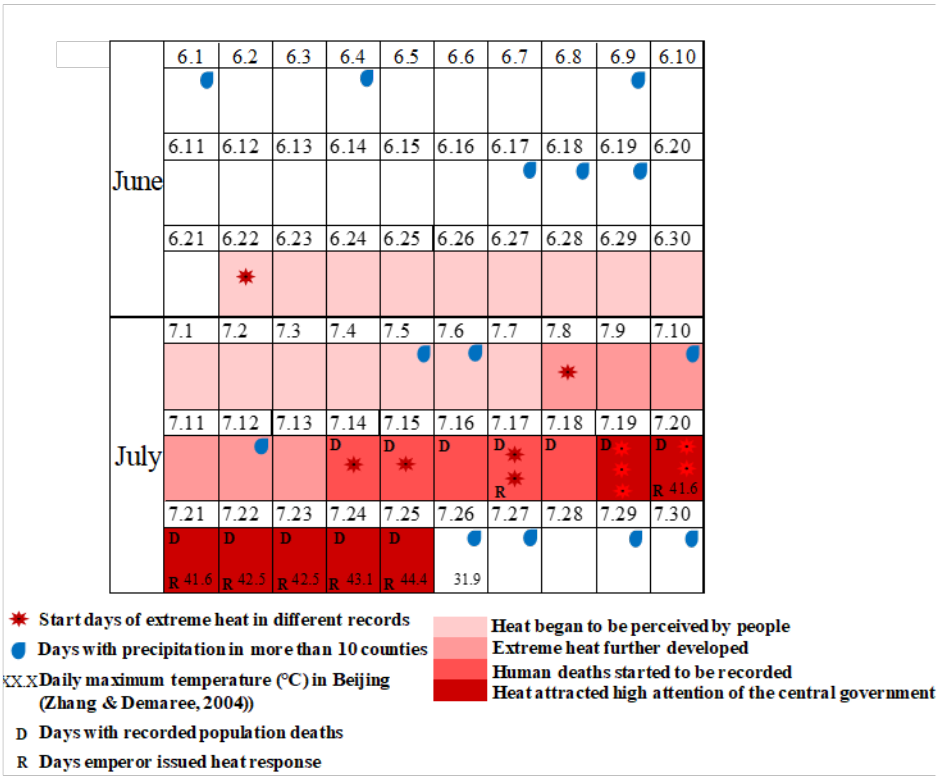

Figure 2: Process over time of 1743 extreme heat (in a form of Calendar)

There are clear records of population deaths beginning on July 14 or July 15 and continuing at least through the end of the July 25 heat wave. R2 shows that in the 26th day of the fifth lunar month (July 17), Emperor Qianlong verbally deployed some countermeasure to the hot weather for the first time. From the 29th day of 5th lunar month to the 5th day of 6th lunar month (July 20 to July 25), the emperor worried about the hot weather almost every day. Yu-Xue-Fen-Cun also show almost no precipitation from July 12th through July 26th.

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

3.2 Spatial pattern of the heat severity in 1743

The map below shows the spatial distribution of extreme heat records and their different severity levels in R1(Fig.3). It can be seen that extreme heat in 1743 occurred mainly in the plains and a few valleys north of the Yellow River. Locations

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with more severe impacts and abundant records were mainly located in the pre-mountain plains east of the Taihang Mountains, e.g., major cities in the eastern foothills of the Taihang Mountains such as Beijing, Baoding, Shijiazhuang, and Xingtai all experienced more severe heat wave events (Level IV). This may have been the consequence of a combination of weather and topographic causes. Level I and II records with relatively mild impacts and abbreviated records are mainly found in the fringes of the records, but are also distributed in the core area. The record classes in the text reflect to some extent the distribution of the degree of heat, but are also influenced by anthropogenic recording factors.

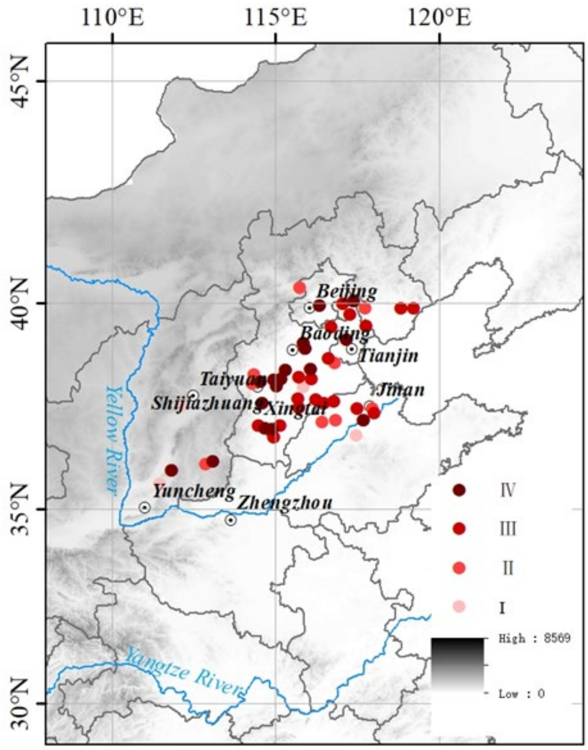

Figure 3: Spatial pattern of the heat severity

3.3 Impact of the 1743 extreme heat

The spatial distribution of impact on human is roughly consistent with extreme heat. Of the 51 records from local annals, 47 involve human deaths. Records of animal and facility impacts, although limited with 5 and 2 respectively, were distributed scattered throughout the study area (Fig.4(b), Fig.4(d)). It suggests that they may not be isolated phenomena in year 1743, but were omitted from the record because they were not emphasized. 10 records about impacts on plant were distributed in the eastern part of Hebei and the northern part of Shandong, which appeared to be the result of compounding with drought. Among them, some records show that extreme heat cause crops to wither or soil moisture to deteriorate, resulting in crop failure or inability to sow. These then affects regional food prices and result in famine and migration of hungry people.

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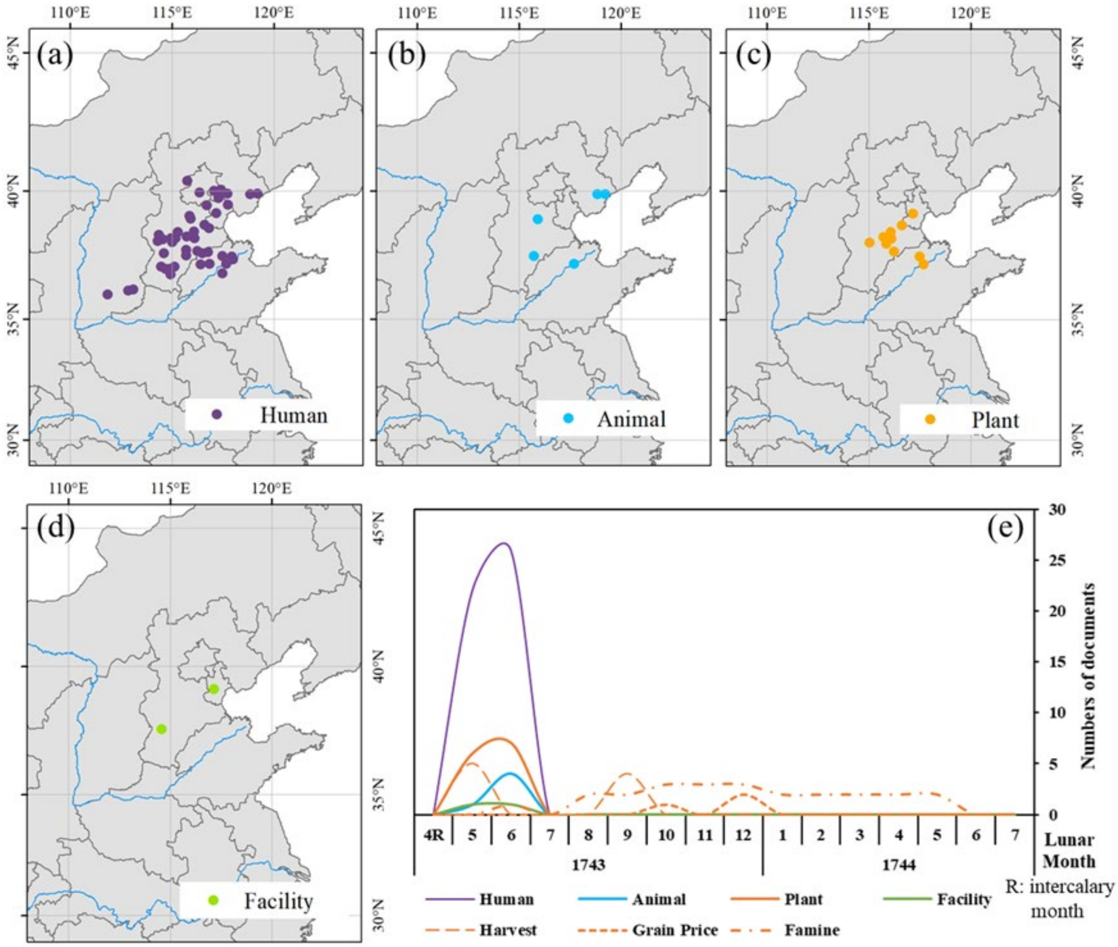

Figure 4: Spatial distribution and time series of extreme heat impacts in 1743

(a)Human; (b)Animal; (c)Plant; (d)Facility; (e)Time serials of impacts.

Damage to crops was also recorded in the extreme heat in 1743. They cause harvest failure, which then leads to higher grain prices, migration of hungry people and other social impact. There were 7 records from local annals documenting grain harvest failure. Among then, 5 reported reduced harvests of wheat (usually harvested in the 5th lunar month) and 4 reported reduced harvests of autumn grain (usually harvested in the ninth lunar month). Of the three records about grain prices rising, two recorded an increase in annual grain prices, and one recorded an increase in grain prices due to autumn crop failure. There were 4 records mentioning people starving in total. Among then, 2 indicated that relief measures to appease the starving lasted from the 8th lunar month to the 5th lunar month of the next year, 1 record indicated that the starving were exempted from taxes that year, and 1 record directly stated that during 6-7th lunar month, many starving people fled to other places. The above records together suggested that the food security impacts of the 1743 heat lasted for more than a year in the social system, which lasted longer than the massive outbreaks of human heat deaths.

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4. Discussion

4.1 What else can be dug from the documents in 1743 extreme heat?

In addition to the above information that can be obtained more directly from the literature, we can further dig out other information related to extreme heat from the historical record through inference and generalization. However, confined to the characteristics of written records, we found that some influence-related patterns can be better found. Whereas quantitative extrapolation of climate elements may be difficult.

4.1.1 Air Temperature inference in 1743 extreme heat

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

In the reconstruction of extreme heat, we also tried to infer temperature range from the human body's heat perception and heat stroke response. There are some of indices and models to measure human perception and health risks under different environmental conditions in different country or region. We referred to NOAA's Heat Index and its Classifications of danger warning under different air temperatures and relative humidities (Tab.4). Based on the descriptions of massive heat-related deaths, it is clear that the Levels III and IV counties (in 3.2) reached the warning level of "Extremely Hot". Using 40-50% humidity, which is the multi-year 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 website of NOAA4. The results indicate that a total of 40 counties in Levels III and IV were likely to have temperatures of 40°C or higher in 1743 extreme heat.

Table 4: Classifications of danger warning of Heat Index (NOAA)[5]

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, and heatstroke POSSIBLE with prolonged exposure and/or physical activity.	36~37°C
Extremely Hot	Heat/Sunstroke HIGHLY LIKELY with continued exposure.	40~43°C

*Calculated at 40~50% humidity.

Although the estimated temperature agrees well with Zhang's results, unlike physical, chemical or biological proxies, textual records can't help establishing a quantitative equation with meteorological elements. Danger warning levels are

[4] *https://www.wpc.ncep.noaa.gov/html/heatindex.shtml*

[5] Heat Index Chart (*https://www.noaa.gov/sites/default/files/2022-05/heatindex_chart_rh.pdf*)

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artificially assigned classifications of general effect on people that do not correspond in a physical sense to individual responses.

4.1.2 Impact transmit chains in 1743 extreme heat

Although the subjective nature of the written documents limits its potential for quantitative reconstruction, subjectivity also means that they focus on the human experience and the impact of extreme weather and climate on human society. Thus, more details about human societies such as how the impact of extreme heat transmit 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 3.3 shows that the main impact transmit chains are: 1) Heat→Human death; 2) Heat→Animal physiological disorder or death; 3) Heat (combined with drought) → Crop damage → Reduced food production → Hungry people/Rising food prices; 4) Heat → Facilities damaged. There is no doubt that impact chain 3) is special because it goes beyond the physical effects of heat on living things or objects. The effects are magnified in society. It has been noted that the impact transmission chain about food security is the main way that extreme climate events affect society in historical time(Fang et al. 2015). This is because food production was a core of the livelihood of people in ancient China. Its impact could further influence higher levels of society. Similarly, it is because of the extra attention that it is given that it occupies a large part of the record. The Preference of recording socio-economic impacts 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 pprovide more insights about extreme heat. Based on the results of this study, comparisons can be made in two directions. One is through spatial comparisons to determine if those areas that were hotter in the 1743 behave the same way in modern times, and the second is to explore responses to the effects of high temperature heat waves by comparing the main effects of the heat waves, in terms of the number of population deaths.

4.2.1 Areas with more severe heat

With the increasing frequency of extreme heat waves, areas suffered more severe heat in different given cases will be at higher risk in the future. In the results of 3.2, cities along Taihang Mountains such as Beijing, Tianjin, Baoding, and Shijiazhuang recorded more severe heat. It seems that in recent years, they are also often reported simultaneously in extreme heat events in North China.

In order to explore whether the extreme heat in the North China in 1743 is spatially consistent with that in modern times, three typical years 2000, 2002 and 2022 are selected for comparison according to the results in 3.2. The daily maximum temperature in summer (from June to August) of 156 meteorological stations in the study area in 2000, 2002 and 2022 were

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obtained from the China Meteorological Data Center. We firstly defined the period of extreme heat in 2000, 2000 and 2002. It began with one or more stations recorded maximum daily temperature higher than 38°C, and ended when there were no stations recording maximum daily temperature higher than 38°C in the following 5 days. The result shows that in 2000, the heat period was long, from the end of June to July 26, and in 2002 it lasted from July 10 to July 19. In 2022, it was the earliest one, mainly in mid to late June (Fig.5). Fig.5 shows the locations of level IV records (in 1743) and where Tmax exceeds 40 °C (in 2000, 2002 and 2022) during the period of extreme heat. Although the extreme heat occurred in different time, the spatial characteristics of Tmax distribution were similar. The black boxes on the map identified areas where severe heat occurred in all four years, and they are mainly in the plains east of the Taihang Mountains. This region is a densely populated and economically distributed area of the North China Plain, and the risk of urban heat waves in these places is of concern in the future.

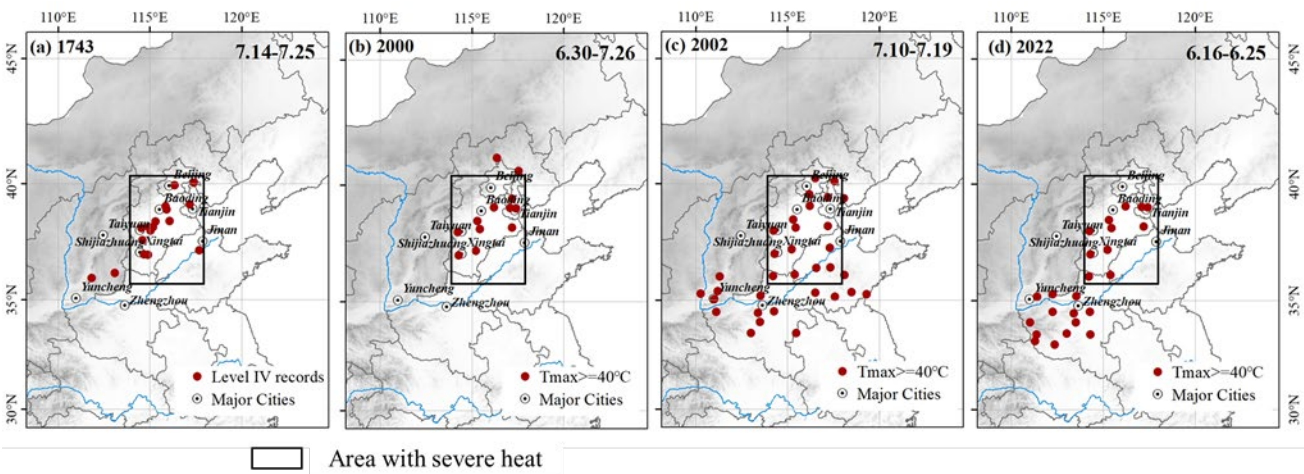

Figure 5: Spatial distribution and time series of extreme heat impacts in 1743

4.2.2 Population deaths due to extreme heat

Humans are the main victims of heat wave disasters. Population health and life safety are core concerns in extreme heat disasters. Of all the effects in the extreme heat of 1743, human deaths were undoubtedly the most conspicuous and shocking. Description of the people death such as “People died suddenly from heat stroke” (supplement1-R1-11&12) and “when it was extremely hot, people died instantly once they touched by the burning air” (supplement1-R1-6) shows that people suffered severe heat sickness in 1743 under high temperature. A letter from a French missionary, A. Gaubil, said that between July 14 and July 25, 11,400 people had died of heat in and around Beijing (Zhang and Demaree 2004). The spatial range in this investigation was undefined, but 2 records from local annals described the number of deaths as “dozens of people per day” (supplement1-R1-11&12). It shows that the number of heat-related deaths in a single county is significant. Compared to modern extreme heat cases, the scale of heat deaths in historical times is considerable (Tab.5).

Tab.5 A comparison of the mortality of the 1743 heat with those of typical modern heat waves

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Climate of the Past Discussions

Year	Region	Days when Daily maximum temperature above 35°C	Number of heat-related deaths
1743	North China	At least ~ 12days: 7.14-7.25	11,400 in Beijing and surroundings
2003	France	15 days: 8.4-8.15	3,548(Alain et al., 2006)
2013	Shanghai, China	33days: 7.2-7.4/7.8-7.11/7.12-7.31/8.3-8.12	167(Sun et al., 2014)
2017	England	10 days: 6.17-6.23/7.5-7.7	1,489(Rustemeyer and Howells, 2021)

In the Qing Dynasty, people in North China mainly engaged in agriculture, and the long-term exposure to high temperatures was the main cause of deaths. In the face of extreme heat, individuals and governments have very limited means of coping. Timely cooling and reducing the exposure of vulnerable populations are feasible approaches. There was a practice of storing ice in winter and using in summer in the Qing Dynasty. But ice was a luxury item and available only in a few places for the elite. The records of "giving ice soup and medicine" and "setting up ice factories and distributing medicine for relief" only appeared in Beijing and Tianjin, and the rest of the county town did not seem to have such conditions. Much-needed cooling measures after heat stroke are difficult to achieve. Measures such as "build pergolas" and "ordering work to stop" recorded in the Factual Record of Qing Dynasty are to reduce the exposure of special groups.

Although deaths have decreased compared to 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 rises rapidly and nonlinearly at high temperatures (Gasparrini et al. 2015). The excess mortality of people with cardiovascular and respiratory diseases due to high temperature is very significant (Cheng et al. 2019). And once a person gets a 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, paying attention to people who work outdoors and those who with underlying diseases are limited but necessary measures to deal with extreme heat.

4.3 How the rest of the Northern Hemisphere behaved in 1743 Summer

What climatic phase was the Northern Hemisphere in in 1743, and were there other regions that experienced similarly high temperature that summer? This is also worth exploring to help us understand the case in a larger spatial and temporal scale. Although higher-resolution heat wave records are relatively difficult to obtain, it is possible to capture the performance of 1743 summer from a long time series. We collected 17 paleoclimatic reconstruction series in the Northern Hemisphere form NOAA (https://www.ncei.noaa.gov/access/paleo-search). They are 5 from Asia, 6 from Europe and 6 from North America. The reconstructed indexes of these studies are temperatures of partial months of warm season (Mar-Sep), summer (Jun-Aug) or partial months of summer. For the year 1743, the degree of warm/cold and the trend of warm/cold in the series are investigated. (1) The degree of warm/cold in 1743 is expressed by a grade. We divided the reconstructed values of a serial over the entire Little Ice Age into four grades by quartiles. The Little Ice Age is defined by the Encyclopedia Britannica as 1301-1850. If the reconstructed sequence is shorter than this period, the calculation is based on the actual start and end time of the serials. (2) The trend of warm/cold is calculated by 11 years (before and after 1743) trend.

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The following map displays the degrees of warm/cold and trend of 1743 summer in different reconstructed sequences in the Northern Hemisphere (Fig.6). The color of circles shows warm summer in Northeast Asia and North America, while Europe is 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 is warming, which is consistent with the integration of cold and warm reconstructions in the Northern Hemisphere over the past millennium(Emile-Geay et al., 2017). 1743 was a period of rising temperatures during the Little Ice Age.

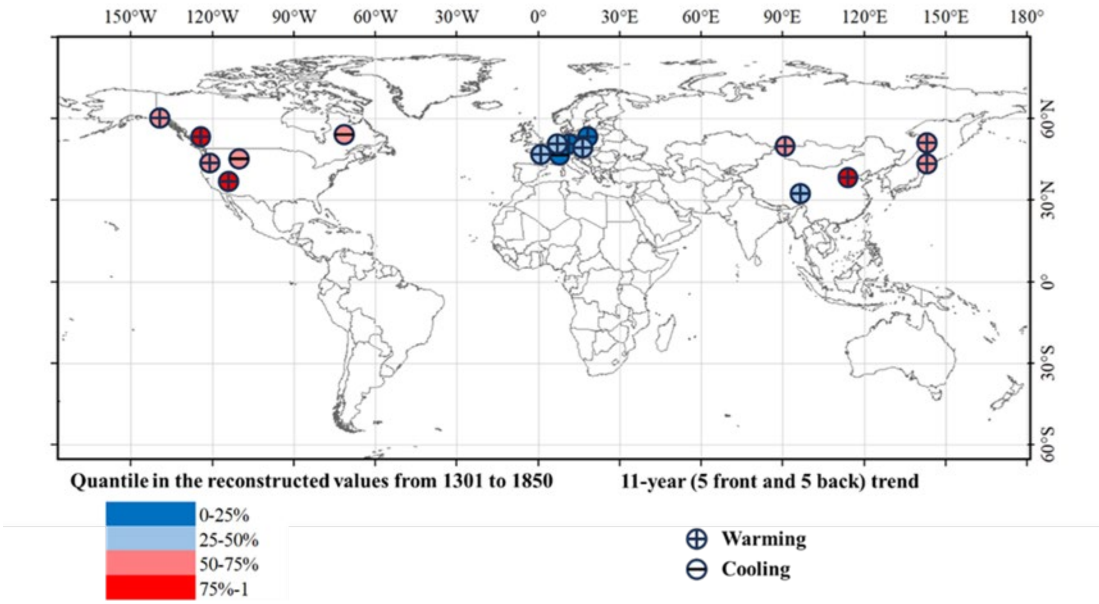

Figure 6: Behavior in the rest of the Northern Hemispher in 1743 Summer

(Davi et al., 2002;Chuine et al., 2004;Meier et al., 2007;Glaser and Riemann, 2009;Dobrovolný et al., 2010;Wetter and Pfister, 2013;Wilson et al., 2014;Wang et al., 2015;Wiles et al., 2015;Luterbacher et al., 2016;Wilson et al., 2019;Martin et al., 2020;Davi et al., 2021;Heeter et al., 2021;Wang et al., 2022;Heeter et al., 2023)

On a global scale, many studies have explored remote associations of extreme heat in North China with Eurasia and North America (Deng et al. 2018;Kornhuber et al. 2019;Kornhuber et al. 2020;Yang et al. 2021). Because they often occur at the same time as westerlies fluctuate more. We are also interested in whether the extreme heat in northern China in 1743 is linked to other parts of the world. However, it is difficult to clear whether short-term heat waves 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 of westerlies had a chain response in the middle and high latitudes of the northern Hemisphere. Therefore, we believe that 1743 may only be a very extreme heat event on a regional scale during a relatively warm period. It is unlike the large-scale extreme heat events and heat waves in the Northern Hemisphere caused by global warming in recent years.

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5. Conclusion

In this research, we referred to 3 kinds of historical materials including local annals, archives and official history books, using methods of textual analysis, grading, classification to display the time development, spatial pattern and characteristics of impacts of the extreme heat in 1743. We discussed the disadvantages and advantages of historical documents in mining the climate eigenvalues and impacts of extreme weather events. The spatial characteristics of extreme heat and the number of deaths caused are compared with typical modern examples. We also discuss climate performance in other regions of the Northern Hemisphere in 1743.

The results show that, most of the Northern Hemisphere was in the phase of an interdecadal temperature rise during the summer of 1743, with East Asia and North America on the warm side. The extreme heat of 1743 in north China occurred in such climate background.

1) The extreme heat of 1743 developed in a gradual manner. Beginning on June 22, people became aware of the unusual heat; after July 8, the heat continued to develop; beginning on July 14, human deaths caused by the heat wave began to be recorded; and beginning on July 19, the severe effects of the heat wave were given high priority by the central government. The heat peaked on July 25 and was later relieved by precipitation. The maximum of daily maximum temperature in 40 counties were likely to reach 40-43 °C.

2) The extreme heat events of 1743 occurred in the plains north of the Yellow River and in the valleys of southwestern Shanxi. The worst heat was distributed in the plains east of the Taihang Mountains, with the areas around Baoding, Shijiazhuang, and Xingtai being the main cities affected. They are also at high risk for heat waves in the North China Plain in modern times.

3) The extreme heat event of 1743 caused damage to human health, plants and animals, and facilities. Of these, the impacts on crops persist in human social systems. The number of deaths from extreme heat waves has decreased compared to the historical period, but population deaths remain the most significant impact event of extreme heat events. Timely cooling and reducing exposure are limited but necessary means to deal with high temperatures in both ancient and modern times.

Data availability

All original textual records in this study have been digitized and organized in Supplement 1.

Author Contributions

Le Tao and **Yun Su** contributed to the study conception and design. Funding acquisition was performed by **Yun Su**. All historical documents are acquired, digitized and processed by **Le Tao**, and mapped by **Le Tao**, **Xudong Chen** and **Fangyu**

Tian. **Xudong Chen** provided the writing outline and **Fangyu Tian** shared ideas to the discussion. The first draft of the manuscript was written by **Le Tao** and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Conflict of Interests

The authors declare that they have no known competing financial or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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