Spatial Patterns of Precipitation Anomalies for 30-yr Warm Periods in China During the Past 2000 Years

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(Received May 13, 2011; in final form February 28, 2012)

ABSTRACT

The spatial patterns of precipitation anomalies during five 30-yr warm periods of 691–720, 1231–1260, 1741–1770, 1921–1950, and 1981–2000 were investigated using a dryness/wetness grading dataset covering 48 stations from Chinese historical documents and 22 precipitation proxy series from natural archives. It was found that the North China Plain (approximately 35°–40°N, east of 105°E) was dry in four warm periods within the centennial warm epochs of 600–750, the Medieval Warm Period (about 900–1300) and after 1900. A wet condition prevailed over most of China during 1741–1770, a 30-yr warm peak that occurred during the Little Ice Age (about 1650–1850). The spatial pattern of the precipitation anomaly in 1981–2000 over East China (25°–40°N, east of 105°E) is roughly consistent with that in 1231–1260, but a difference in the precipitation anomaly appeared over the Tibetan Plateau. The spatial patterns of the precipitation anomalies over China varied between all five 30-yr warm periods, which implies that the matching pattern between temperature and precipitation change is multiform, and the precipitation anomaly could be positive or negative when a decadal warm climate occurs in different climate epochs. This result may provide a primary reference for the mechanism detection and climate simulation of the precipitation anomaly of the future warm climate.

Key words: spatial patterns, precipitation anomalies, 30-yr warm periods, past 2000 years, China

Citation: Hao Zhixin, Zheng Jingyun, Ge Quansheng, et al., 2012: Spatial patterns of precipitation anomalies for 30-yr warm periods in China during the past 2000 years. *Acta Meteor. Sinica*, **26**(3), 278–288, doi: 10.1007/s13351-012-0302-1.

1. Introduction

Climate change associated with global warming may alter precipitation patterns over the globe. For example, pronounced increases in precipitation over the past 100 years have been observed in eastern North America, southern South America, and northern Europe; decreases in rainfall have been observed in the Mediterranean, most of Africa, and southern Asia (Karl et al., 2009). In China, as seen from the observed precipitation dataset since 1951, compared with the relative cold period of 1951–1980, the precipitation pattern during the warming period of 1981–2000 was characterized by flooding in the south and drought in the north (Zhao and Zhou, 2006). There were several extreme flooding events in the middle and lower reaches of the Yangtze River over the past three decades, i.e., 1981, 1993, 1996, 1998, and 1999 (Wang and Ding, 2008), while extreme drought occurred in North China in 1981, 1986, 1988, 1989, 1992, and 1997 (Zhang et al., 2003). These drought years are associated with the weakness of the East Asian summer monsoon, which has been evident since the end of the 1970s (Wang, 2001, 2002). Because these events have occurred within the context of global warming, there is a question of whether global warming could change the spatial pattern of precipitation in China in the future. This question motivated us to make a survey using long-term precipitation and temperature proxy datasets. The past 2000 years have seen the centennial epochs of the Medieval Warm Period (MWP; about 900–1300), the Little Ice Age (LIA; about 1650–

Supported by the Innovation Project of the Chinese Academy of Sciences (KZCX2-YW-Q1-01, XDA05080100), National Basic Research and Development (973) Program of China (2010CB950100), National Science and Technology Support Program of China (2007BAC03A01), and National Natural Science Foundation of China (41071029).

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1850), and the Present Warm Period (PWP). These periods could serve as sample warm intervals to study the above question.

In previous studies, some focused on the matching pattern between temperature and precipitation change at decadal to centennial scales. Zheng (1983) studied the spatial precipitation pattern within cold and warm decades using yearly dryness/wetness grading data in China during 1470–1970 and found that the climate was in a dry condition in the west of China and in a wet condition in the east of China during the cold decades, and it shifted to the opposite pattern in the warm decades. Wang et al. (1993) compared the spatial pattern of dryness/wetness over eastern China between the MWP and LIA at the centennial scale. They found that the precipitation decreased in North China and increased in the south of the Yangtze River during the MWP, but it increased in the North China Plain and decreased in the south of China during the LIA. However, limited by the rarity of reconstructed precipitation series, many studies have to narrow their research domain to a single site or a small region rather than a large portion of China (Wang et al., 2003). Fortunately, during the last 10 years, high-resolution precipitation reconstructions covering the past 2000 years have been widely developed for the whole of China. These reconstructions are derived from historical documents and natural archives, including tree rings, ice cores, sediments, and stalagmites. It is possible to investigate the spatial patterns of precipitation anomalies by mapping these multi-proxies at the decadal timescale.

Over the past few decades, many long-term temperature proxies have been reconstructed in China from historical documents, stalagmites, sediments, tree rings, and ice cores (e.g., Hong et al., 2000; Ge et al., 2003; Tan et al., 2003; Thompson et al., 2006; Liu et al., 2007). A synthesized regional assessment of most of the peer-reviewed temperature reconstructions showed that three climate epochs, i.e., the MWP, the LIA, and the PWP, existed over the whole China during the past 2000 years. An evident centennial warm epoch during 600–750, before the MWP, also dominated over central eastern China and the Tibetan Plateau (Ge et al., 2003, 2010). These reconstructions provide a reliable temperature proxy to identify warm intervals to study the spatial patterns of precipitation anomalies over the past 2000 years.

The goal of this study is to compare the spatial patterns of precipitation anomalies between warm periods from different centennial climate epochs. To achieve this goal, we first identify five 30-yr warm periods within the PWP, the LIA, the MWP and the warm epoch of 600–750 using temperature reconstructions. Second, we collect published precipitation reconstruction or dry/wet proxy series with a high time resolution ($\leqslant$ 30 yr). We then identify the precipitation anomaly for each warm period from each precipitation reconstruction, and we map the precipitation anomaly with the temperature information. Finally, we analyze the spatial patterns of precipitation anomalies during different warm periods, and discuss the implications and uncertainties of the study.

2. Data and method

2.1 Data sources

Two kinds of data were used in this study: temperature reconstructions during the past 2000 years and precipitation proxies derived from Chinese historical documents and natural evidences.

2.1.1 Temperature reconstructions

Over the recent decade, regional proxy temperature series with lengths of 500–2000 yr have been reconstructed for China using tree rings with a 1–3-yr temporal resolution, annually resolved stalagmites, decadal resolved ice-core information, historical documents with a temporal resolution of 10–30 yr, and lake sediments on decadal to century timescales. A regional temperature assessment was conducted by Ge et al. (2010) using 23 published proxy temperature series over China spanning the last 2000 years in five climate regions: Northeast, central East, Southeast, Northwest, and the Tibetan Plateau. Since large uncertainties were found for the period prior to the 16th century and a high level of consistency was identified in all regions during the past 500 years, the time resolution for the five regionally coherent temperature series reconstructed from the multi-proxy data was only 100 yr. Thus, we used winter half-year (October–April) temperature series over the middle-lower reaches of the Yellow River and Yangtze River to identify the 30-yr warm periods. This temperature series was reconstructed using the phenological cold/warm events recorded in Chinese historical documents at a time resolution of 10–30 yr, and it provided quantitative temperature anomalies (with respect to the 1951–1980 climatology) through a statistical calibration against instrumental temperature measurements (Ge et al., 2003). The National Research Council's report (2006) of surface temperature reconstructions for the last 2000 years presented this temperature reconstruction as a reconstruction paradigm successfully developed in a repeatable and consistent way in East Asia from historical archives.

2.1.2 Precipitation reconstructions

a) Dryness/wetness grades from Chinese historical documents

A 48-station (see Fig. 1 for distribution map) yearly dryness/wetness grading dataset for eastern China (approximately 25°–40°N and east of 105°E) from 501 to 2000 was constructed from ancient Chinese writings, local gazettes, and historical drought/flood archives. This dataset was graded from 1 (very wet) to 5 (very dry) with a frequency distribution of 10%, 20%, 40%, 20%, and 10%, respectively (Zhang, 1996). These grades represent precipitation anomalies according to the mean conditions in the period from 501 to 2000. Due to wars, dynastic alternation, and changing central governmental domains, the number of written records contained in historical documents is inconsistent throughout all historical periods. Generally, the data are less available before 1470, but after 1470, this dataset is of high quality. This dataset has been successfully used to analyze precipitation variability, extreme events during the past 2000 years, and the intensity of the East Asian monsoon at the end of the Tang Dynasty (Zheng et al., 2006; Yancheva et al., 2007).

b) Precipitation proxies from natural archives

A total of 22 precipitation proxy series with lengths of 300–2000 yr in China were collected in this study. These series have annually resolved tree rings, a 1–16-yr time resolution in stalagmites, a 1–10-yr resolution in ice cores, and 10–30-yr resolved sediments (see Table 1 for details and Fig. 1 for the distribution). Most of these series are located in the western part of China. Some proxies indicated precipitation during the summer monsoon season rather than annual precipitation, but because the summer monsoon

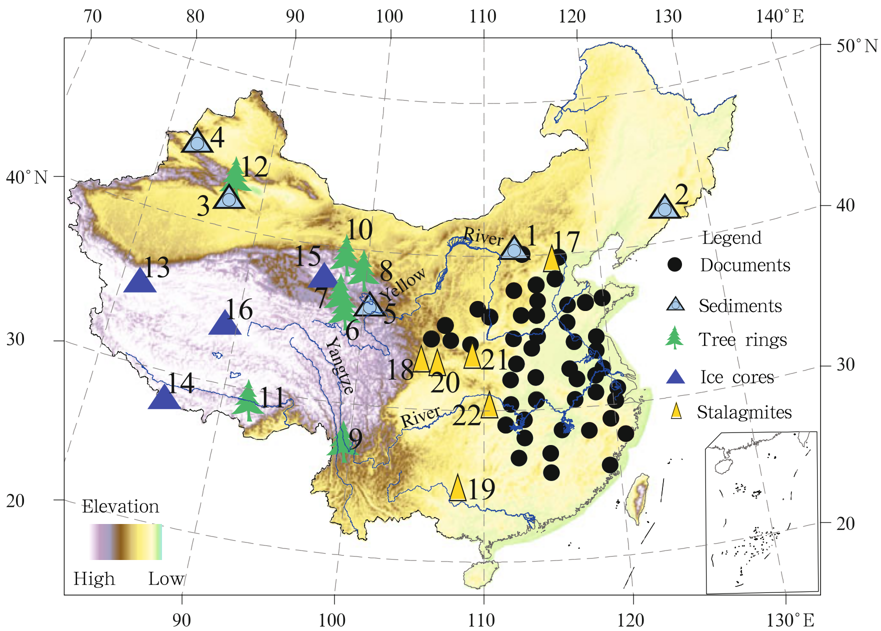

Fig. 1. Location of each precipitation proxy series. See Table 1 for the series number and other detailed information.

Table 1. Information of precipitation proxy series derived from natural archives

Series No.	Region	Location	Proxy type*	Measurement and interpretation	Starting–ending year	Resolution (yr)	References
1	99-yr core in Daihai Lake	40.57°N, 112.68°E	SD	TOC%, Annual precipitation	10000BC –1950AD	15	Xiao et al. 2006
2	Xiaolongwan Lake	42.30°N, 126.35°E	SD	$\delta^{13}C_{org}$, Spring drought index	410–2000AD	1	Chu et al., 2009
3	Bosten Lake	42°N, 87°E	SD	Pollen ratios of Artemisia and Chenopodiaceae, effective humidity	1000–2000AD	10–25	Chen et al., 2006
4	Aibi Lake	45.02°N, 82.9°E	SD	$\delta^{13}C_{org}$, effective humidity	590–2000AD	30	Wu et al., 2004
5	Qinghai Lake	36.60°N, 100.50°E	SD	Carbonate, annual precipitation	1050–2000AD	20	Shen et al., 2001
6	Dulan	36.08°N, 98.47°E	TR	Ring width of Qilian juniper, June–July precipitation	850–2000AD	1	Liu et al., 2006
7	Northeast of Qaidam basin	37°N, 98°E	TR	Ring width of Qilian juniper, June–July precipitation	565–2001AD	1	Shao et al., 2006
8	Central Qilian Mountains	38.70°N, 99.70°E	TR	Ring width of Qilian juniper, July–August precipitation	775–2006AD	1	Zhang et al., 2011
9	Southeastern Tibetan Plateau	27.50°N, 99.50°E	TR	Palmer Drought Severity Index, June–August precipitation	1440–2007AD	1	Fang et al., 2010
10	Hexi Corridor	39.55°N, 98.08°E	TR	Ring width of Qilian juniper, June–July precipitation	1390–2007AD	1	Yang et al., 2010
11	South central Tibet	29.30°N, 92.00°E	TR	Ring width of Tibetan juniper, June–July precipitation	1480–2008AD	1	Liu et al., 2011
12	Urumuqi	43.28°N, 87.22°E	TR	Ring width of spruce, May precipitation	1667–1993AD	1	Yuan et al., 2002
13	Guliya	35.28°N, 81.48°E	IC	Net accumulation, summer monsoon precipitation	351–1990AD	1–10	Yao et al., 1997
14	Dasuopu	28.38°N, 85.72°E	IC	Net accumulation, South Asian monsoon precipitation	1450–2000AD	10	Thompson et al., 2000
15	Dunde	38.10°N, 96.40°E	IC	Net accumulation, annual precipitation	1600–1995AD	1	Yao et al., 1991
16	Puruogangri	34°N, 89°E	IC	Accumulation, annual precipitation	1600–1999AD	1	Yao et al., 2008
17	Shihua Cave	39.80°N, 115.90°E	St	$\delta^{18}O$‰, annual precipitation	1500–2000AD	3	Li et al., 1998
18	Wanxiang Cave	33.32°N, 105°E	St	$\delta^{18}O$‰, Asian monsoon precipitation	192–2003AD	1–5	Zhang et al., 2008
19	Dongge Cave	25°N, 108.10°E	St	$\delta^{18}O$‰, Southwest monsoon precipitation	1000–2000AD	4–5	He et al., 2005
20	Dayu Cave	33.13°N, 106.30°E	St	$\delta^{18}O$‰, summer monsoon in central China	1249–1983AD	2–3	Tan et al., 2009
21	Buddha Cave	33.67°N, 109.08°E	St	$\delta^{13}C$‰, wet/dry condition	725–1995AD	1–4	Paulsen et al., 2003
22	Heshang Cave	30.45°N, 110.42°E	St	$\delta^{18}O$‰, Southwest monsoon	7500BC–2001AD	16	Hu et al., 2008

*SD: sediments; TR: tree rings; IC: ice cores; St: stalagmites; TOC: total organic carbon. The geographical locations of these proxies are shown in Fig. 1.

precipitation accounts for more than half of the annual rainfall in China, this was used to represent the annual precipitation anomaly at the reconstructed regions.

2.2 Method

2.2.1 Identification of 30-yr warm periods

A 30-yr-resolution temperature reconstruction series (Fig. 2) in the middle and lower reaches of the Yellow River and Yangtze River for the past 2000 years (Ge et al., 2003) was used to determine 30-yr warm periods from the PWP, the LIA, the MWP, and another centennial warm epoch of 600–750 before the MWP. Note that the warm epochs of 600–750 and 900–1300 were also evident in the temperature series of Northeast China and the Tibetan Plateau (Fig. 2), respectively, both of which were reconstructed from multi-proxy data (Ge et al., 2010). The cold epoch of 1650–1850 was found in all three regional temperature reconstructions. We selected the warm peaks of 691–720, 1231–1260, and 1741–1770 to represent the 30-yr warm periods within the typical climate epochs of 600–750, 900–1300, and 1650–1850, respectively. Moreover, we selected 1921–1950 and 1981–2000 to represent the 30-yr warm periods within the PWP. Note that 1981–2000 has only 20 yr because most of the proxy data did not cover the period after 2000.

2.2.2 Identification of precipitation anomalies within 30-yr periods

The original drought/flood records in historical times had an uneven temporal distribution, i.e., earlier records, especially before 1470, were less available, which caused inhomogeneity in the dryness/wetness grading data of the past 2000 years (Man, 2000). This uneven temporal distribution is mainly attributed to the availability of surviving historical written records. To avoid the effect of data scarcity and to maintain a homogeneous database, the dry-wet index was adopted to identify the precipitation anomalies within the 30-yr periods of 691–720, 1231–1260, 1741–1770, 1921–1950, and 1981–2000 using the 48-station dryness/wetness grading data from Chinese historical documents. The 30-yr dry-wet index (Zheng et al., 2006) for each station is defined as follows:

$$\mathrm{Dw}_{st} = 2P_{st}^1 + P_{st}^2 - P_{st}^4 - 2P_{st}^5, \tag{1}$$

where s represents a single site (s = 1, 2, ..., 48); t represents the periods 691–720, 1231–1260, 1741–1770, 1921–1950, and 1981–2000; Dw_{st} is the dry-wet index for the 30-yr period; and p_{st}^k is the frequency of occurrence of grade k in the 30-yr period, where k = 1, 2, 4, 5 represents severe flood, flood, drought, and severe drought, respectively. From this definition, it is easy to see that when $\mathrm{Dw}_{st} > 0$, the climate is in a wet condition, and when $\mathrm{Dw}_{st} < 0$, the climate is in a dry condition. The absolute value of Dw_{st} indicates the dry-wet severity, i.e., a larger value indicates a greater severity.

The precipitation anomaly for natural proxies is identified as the deviation from the mean of the past 2000 years (if the length of the series is longer than 2000 yr) or the mean of the whole series (if the length of the series is less than 2000 yr) derived from the 22 precipitation proxies. Note that the time resolution

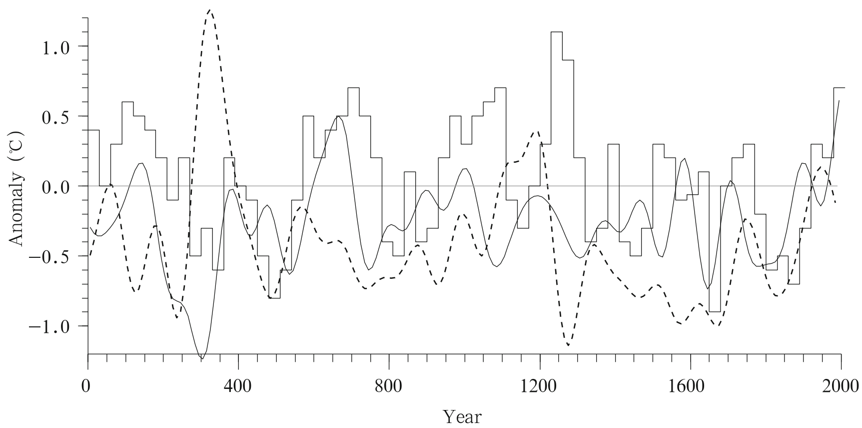

Fig. 2. Winter half-year temperature anomalies (with respect to the 1901–1950 climatology) in the middle and lower reaches of the Yellow River and Yangtze River (bold bar line) reconstructed from historical phenological cold/warm events, and regionally coherent temperature series of Northeast China (dashed line) and the Tibetan Plateau (solid line) reconstructed from multi-proxy data for the past 2000 years.

is from 1 to 30 yr for different series. Thus, when the time resolution is less than 30 yr, the mean values over the periods of 30 yr are calculated to identify the precipitation anomaly in the study period.

3. Results

Figure 3 presents the spatial precipitation patterns for the five warm periods of 691–720, 1231–1260, 1741–1770, 1921–1950, and 1981–2000. The anomalies shown in each 30-yr period were plotted as the 30-yr mean departure from the mean of 1–2000 or the mean value of the whole series when the length of the series is shorter than 2000 yr.

Because few data are available in the historical documents (23 stations) and natural proxies (5 prox-

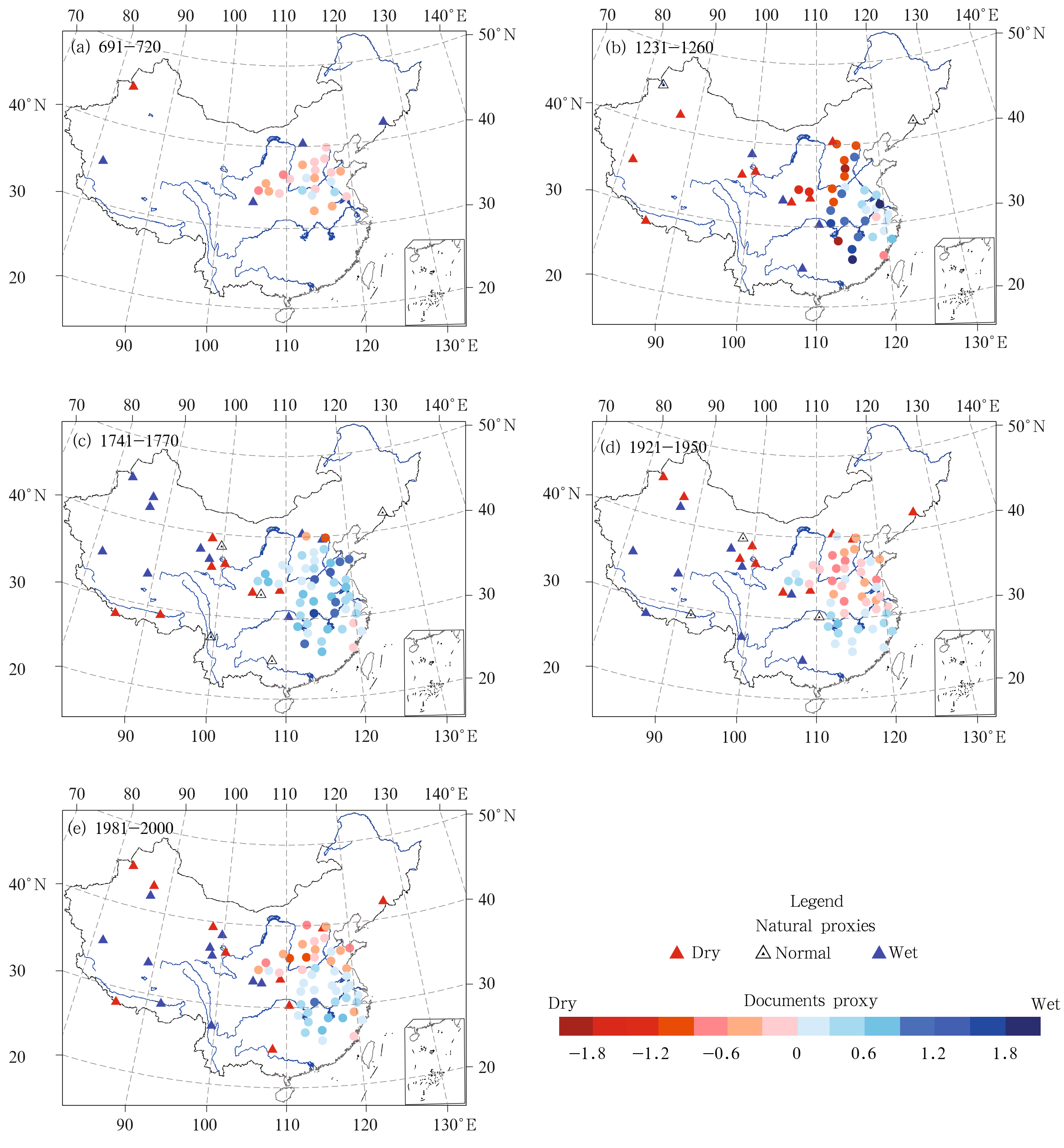

Fig. 3. Spatial patterns of precipitation anomalies within the periods (a) 691–720, (b) 1231–1260, (c) 1741–1770, (d) 1921–1950, and (e) 1981–2000.

ies) for the other areas during the period from 691 to 720, the precipitation anomaly of 691–720 is only presented between 32° and 40°N in Fig. 3a. The pattern indicates that the climate was dry in the North China Plain (approximately 35°–40°N, east of 105°E), although it was slightly wet in central Henan Province, the southwest of Shandong Province and the south of Gansu Province. Moreover, the records from the lake sediments in Daihai and Xiaolongwan suggest that it was wet from the northern edge of the North China Plain to the south of northeastern China. Because only two precipitation proxies are available for the Xinjiang Uygur Autonomous Region and the Tibetan Plateau, it is difficult to illustrate the precipitation anomaly pattern for West China.

Figure 3b provides the spatial distribution of precipitation anomalies during the period from 1231 to 1260. Compared with the last warm period of 671–720, more data (33 stations from historical documents and 14 proxies from natural archives) are available in this period. Opposite precipitation anomalies were found in North China and the Tibet versus the south of the Yellow River. The climate was dry in most of the North China Plain, Northwest China, and the Tibetan Plateau, while a wet climate was found in the south of the Yellow River (approximately 25°–35°N, east of 105°E). However, a wet climate is shown in the tree-ring records in Dulan (elevation 3800–4200 m) and northeast of the Tibetan Plateau and in a stalagmite in Wanxiang Cave (elevation 1150 m), which suggests that the climate was wet in the high altitude area in the east of Northwest China. These features, i.e., dry in the North China Plain and wet in the lower reaches of the Yangtze River, were also presented by Zhang et al. (1997) and Qian et al. (2003), respectively. For example, a dry climate in the mid-lower reaches of the Yellow River in 1231–1260 was reported by both Zhang et al. (1997) and Qian et al. (2003). Zhang et al. (1997) also concluded that it was wet in the south of the lower Yangtze River during 1231–1260.

The spatial patterns of the precipitation anomalies from 1741 to 1770 are presented in Fig. 3c, which shows that the climate was wet over most of China, although it was dry in the southern and northeastern regions of the Tibetan Plateau, the Qinling Mountains, and scattered areas in Fujian and Zhejiang provinces in the southeast of China. This pattern is similar to that found by Zhang et al. (1997) and Qian et al. (2003), both of whom showed that it was wet from the lower reaches of the Yellow River to the lower reaches of the Yangtze River and dry in the south of the Yangtze River, with the wettest areas in the lower reaches of the Yellow River and Huaihe River. Although our study also illustrates that there were slightly dry regions in Southeast China, the wet climate condition dominated the regional mean of 1741–1770 according to Zhang et al. (1997).

In Fig. 3d, the opposite pattern, with less precipitation in the north of the Yangtze River and more precipitation in the south of the Yangtze River, can be found during the period of 1921–1950. Moreover, a wet condition prevailed in the Tibetan Plateau, but a dry condition dominated in Northwest China. This result is supported by the report of Climate and Environment Changes in China (Qin et al., 2005), in which the spatial patterns of decadal precipitation anomalies in the 1920s, 1930s, and 1940s were analyzed according to the observational data. This report found that most of China was in a dry condition from the 1920s to 1940s. The exception was south of 25°N, Tibet, and the east of Xinjiang Uygur Autonomous Region in the 1920s; central China, Tibet, and central Xinjiang in the 1930s; and the south of China and the upper valleys of the Yangtze and Yellow rivers in the 1940s. In addition, our finding also agrees well with the result from Zhao et al. (2011), who found that Nanjing, located at the lower reaches of the Yangtze River, was in a dry condition during the period of 1921–1950.

Figure 3e shows that it was dry in the North China Plain, including the southern part of Northeast China, but slightly wet in the south of the Huaihe River from 1981 to 2000. This spatial pattern of precipitation anomalies has been reported in numerous studies (e.g., Zhang et al., 2003; Zhao and Zhou, 2006; Wang and Ding, 2008). This pattern features flooding in the south and drought in the north associated with the weakness of the East Asian summer monsoon since the end of the 1970s (Wang, 2001, 2002). Moreover, most of the precipitation proxies show that a wet condition prevailed over the Tibetan Plateau and the southwest of China, while a dry condition prevailed over northern Xinjiang and western Gansu Province.

By comparing the above five spatial patterns of precipitation anomalies during the warm periods, except for the wet condition in the North China Plain during 1741–1770 (the warm peak of the LIA), a dry condition was found in the North China Plain for the other four warm periods within the centennial warm epochs, including the PWP, the MWP, and the warm epoch of 600–750. Moreover, the spatial pattern of the precipitation anomaly in 1981–2000 over the east of China (25°–40°N, east of 105°E) is consistent with that in 1231–1260, but different from the precipitation anomaly that appears over the Tibetan Plateau.

In general, our study shows that the spatial patterns of the precipitation anomaly over China varied in all five 30-yr warm periods. This result suggests that the temperature and precipitation changes appear with multiple combinations, and the precipitation could be positive or negative when decadal warm climates occurred in the different centennial-scale climate epochs. Moreover, the variation of precipitation difference between North and South China caused by cold/warm temperature changes was more evident than that between West and East China (Zheng, 1983).

Liu et al. (2009) used ECHAM (European Centre Hamburg Model) and ECHO-G (ECHAM version 4 atmosphere model coupled with Hamburg Ocean Primitive Equation–General Circulation Model) models to simulate the spatial patterns of the annual mean precipitation and global monsoon precipitation of three 30-yr periods, including 1185–1214 in the MWP, 1685–1714 in the LIA, and 1961–1990 in the PWP. They found an increase of total rainfall in the Asian monsoon region in the MWP and PWP and less precipitation in the LIA; the simulated changes of the global monsoon intensity in the 20th century have a spatial pattern that differs from that during the MWP. These changes could be due to both the increase of atmospheric greenhouse gases and incoming solar radiation. Looking at the detailed precipitation patterns, the total annual rainfall for the MWP increased in North and South China, which is different from our results. The possible causes of this difference may be the spatial resolutions of the model outputs, the different periods that were selected, and the uncertainty of the proxies. However, Shen et al. (2009) used proxy data and millennium model simulations to examine the precipitation patterns during the past 500 years. They found that the increased frequency of the drought-in-north/flood-in-south spatial pattern over eastern China during the last two decades of the 20th century was unusual in the past five centuries, which is consistent with our results for 1981–2000. Their results also well support our reconstructed spatial patterns of precipitation anomalies in 1741–1770 and 1921–1950.

4. Conclusions

This paper investigated the spatial patterns of precipitation anomalies for five 30-yr warm periods (1981–2000, 1921–1950, 1741–1770, 1231–1260, and 691–720) within centennial climate epochs during the past 2000 years by analyzing precipitation proxies from tree rings, stalagmites, sediments, ice cores, and a dryness/wetness grading dataset of 48 stations from Chinese historical documents. The results show that the North China Plain (approximately 35°–40°N, east of 105°E) was dry in four warm periods (i.e., 1981–2000, 1921–1950, 1231–1260, and 691–720) within the centennial warm epochs including the PWP, MWP, and the warm epoch of the 570s–770s. The spatial pattern of precipitation anomalies in 1981–2000 over the east of China (25°–40°N, east of 105°E) is roughly consistent with that in 1231–1260, except for the difference of the precipitation anomaly over the Tibetan Plateau. However, the spatial patterns of the precipitation anomaly over China varied from one period to another for all five 30-yr warm periods, which implies that the matching pattern between temperature and precipitation change is multiform and not fixed upon a decadal warm climate that occurs in different climate epochs.

In 691–720, it was dry in the North China Plain and wet from the northern edge of the North China Plain to the south of Northeast China. In 1231–1260, a dry condition was found in most of the North China Plain, Northwest China, and the Tibetan Plateau, but a wet condition was found in the south of the Yellow River (approximately 25°–35°N, and east of 105°E) and in the high altitude area of the northeastern Tibetan Plateau. In 1741–1770, a wet climate prevailed over most of China, except for a dry condition in some scattered areas, such as the southern and northeastern Tibetan Plateau and the Qinling Mountains. In 1921–1950, a dry condition dominated in the north of the Yangtze River and the north of the Tibetan Plateau, while a slightly wet condition prevailed over the south of the Yangtze River and the Tibetan Plateau. In 1981–2000, it was dry in most of North China and wet in the south of Huaihe River, most of the Tibetan Plateau and the southwest of China.

It is worth noting that during most of the warm decades, a dry condition is prevalent in the Yellow River and Huaihe River valleys (except 1741–1770), and the Yangtze River valley is in a wet condition, but not in the period of 691–720. This result may provide a reference for mechanism detection and climatic simulations of the precipitation anomaly patterns in the future warming climate, although the main spatial patterns of the precipitation anomalies in the context of the warming periods are difficult to be summarized statistically based on our very few cases.

It should be noted that the proxy-based reconstructions, for both temperature and precipitation series, are subject to uncertainties mainly due to dating, quantitative proxy interpretation of climatic parameters, spatial representation, and calibration of proxy data during the reconstruction procedure as well as the available sample numbers. For example, although the Chinese historical documents are well known for their consistency in writing format, language conciseness, completeness and exact dating, we still cannot completely exclude uncertainties in the results due to the inherent deficiencies of the documentary data, especially those resulting from the changes of observers and the inhomogeneity of the data recording caused by uneven spatial and temporal distributions. Thus, the spatial patterns of precipitation anomalies and other conclusions shown in the present study may involve these inherent deficiencies and must be viewed as somewhat speculative. It is imperative to perform more detailed studies in the future, not only for more long-term climate reconstructions, especially temperature and precipitation proxies prior to 1500, but also for long-term spatial pattern changes derived from multi-proxies with different timescales, especially those at decadal, multi-decadal, and centennial scales.

Acknowledgments. The reviewers offered useful comments and suggestions that have helped to improve the quality of this manuscript.

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