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Rates of temperature change in China during the past 2000 years

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Using 24 proxy temperature series, the rates of temperature change in China are analyzed at the 30- to 100-year scales for the past 2000 years and at the 10-year scale for the past 500 years. The results show that, at the 100-year scale, the warming rate for the whole of China in the 20th century was only 0.6±1.6°C/100 a (interval at the 95% confidence level, which is used hereafter), while the peak warming rate for the period from the Little Ice Age (LIA) to the 20th century reached 1.1±1.2°C/100 a, which was the greatest in the past 500 years and probably the past 2000 years. At the 30-year scale, warming in the 20th century was quite notable, but the peak rate was still less than rates for previous periods, such as the rapid warming from the LIA to the 20th century and from the 270s–290s to 300s–320s. At the 10-year scale, the warming in the late 20th century was very evident, but it might not be unusual in the context of warming over the past 500 years. The exact timing, duration and magnitude of the warming peaks varied from region to region at all scales. The peak rates of the 100-year scale warming in the AD 180s–350s in northeastern China as well as those in the 260s–410s and 500s–660s in Tibet were all greater than those from the mid-19th to 20th century. Meanwhile, the rates of the most rapid cooling at scales of 30 to 100 years in the LIA were prominent, but they were also not unprecedented in the last 2000 years. At the 10-year scale, for the whole of China, the most rapid decadal cooling in the 20th century was from the 1940s to 1950s with a rate of –0.3±0.6°C/10 a, which was similar to rates for periods before the 20th century. For all regions, the rates of most rapid cooling in the 20th century were all less than those for previous periods.

China, past 2000 years, rates of temperature change

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Studying climate change over the past 2000 years is an important activity in the Past Global Changes (PAGES) project, and it is essential to better understanding climate variability and provides background knowledge necessary for improving predictions of future changes [1]. Assessment of uncertainties in our understanding of past global temperature change is a focus of the IPCC's Fourth Assessment Report (AR4) and allows us to better reveal the causes of current global warming. Recently, many high-resolution temperature proxy series have been reconstructed at global, hemispheric, regional and local scales [2–4]. The Surface Temperature Reconstructions for the Last 2000 Years report [5] concluded that large-scale surface temperature reconstructions yield a generally consistent picture of temperature trends during the preceding millennium, including a relatively warm period centered around AD 1000 and a relatively cold period centered around AD 1700, and that the global mean surface temperature was higher during the last few decades of the 20th century than during any comparable period in the preceding four centuries with a high level of confidence. However, less confidence can be placed in large-scale surface temperature reconstructions for the period from AD 900 to 1600. The IPCC AR4 [6] showed that the average North-

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ern Hemisphere temperatures during the second half of the 20th century were very likely higher than those during any other 50-year period in the last 500 years and likely the highest in at least the past 1300 years, and that the rate of warming over the last 100 years (1906–2005) was 0.74±0.18°C/100 a and most of the observed increase in global average temperatures since the mid-20th century is *very likely* (>90% probability) caused by the observed increase in anthropogenic greenhouse gas concentrations [7]. Has rapid warming such as that in the 20th century occurred previously, especially during the past 2000 years? This is a key issue in understanding the forces of climate warming in the 20th century; however, few studies so far have addressed this question.

In China, much effort has been spent in the last few decades to reconstruct regional proxy temperature series with lengths of 500–2000 years from historical documents [8–15], tree rings [16, 17], stalagmites [18], ice cores [19], and lake sediments [20–24]. Uncertainty analysis of these regional reconstructions indicates that warming during the 10–14th centuries in some regions might be comparable in magnitude to the warming of the last few decades of the 20th century that was unprecedented in the past 500 years [25]. In this paper, we assess the uncertainty in the warming rates and the difference of the warming rates between the recent warming period and historical warming periods using regional proxy temperature series for China.

1 Data and method

In this study we used 24 regional proxy temperature series (Table 1), 23 of which have been used by Ge et al. [25] and another one was annual temperature series (TB2) indicated by δ^{18}O‰ from peatland in Hongyuan (32.77°N, 102.50°E) [22]. These 24 regional proxy temperature series were grouped into five regions: northeast (NE), central east (CE), southeast (SE), northwest (NW) and Tibet (TB). There were five series for NE, eight for CE, five for SE, one for NW and five for TB (Figure 1). Although these series were derived from different proxies, such as tree rings, historical documents, stalagmites, ice cores, and lake sediments, they provide quantitative estimates of past temperatures. As seen in Table 1, nine of the series represent annual temperatures [8, 19, 20, 22, 23], while the others represent seasonal temperatures [9–18, 21, 24]. In addition, our previous study [25] demonstrated that the proxies of seasonal temperatures can explain 44%–90% of the variability of annual temperature within the instrumental calibration period (Table 2).

Most of the 24 series have 10-year or higher temporal resolution; therefore, 10-year resolution was chosen in this study. To obtain the same temporal resolution, mean values over periods of 10 years were used for original data with high resolution (<10-year, for tree rings and stalagmites) and linear interpolation was applied to original data with low resolution (>10-year, for lake sediment and peatland).

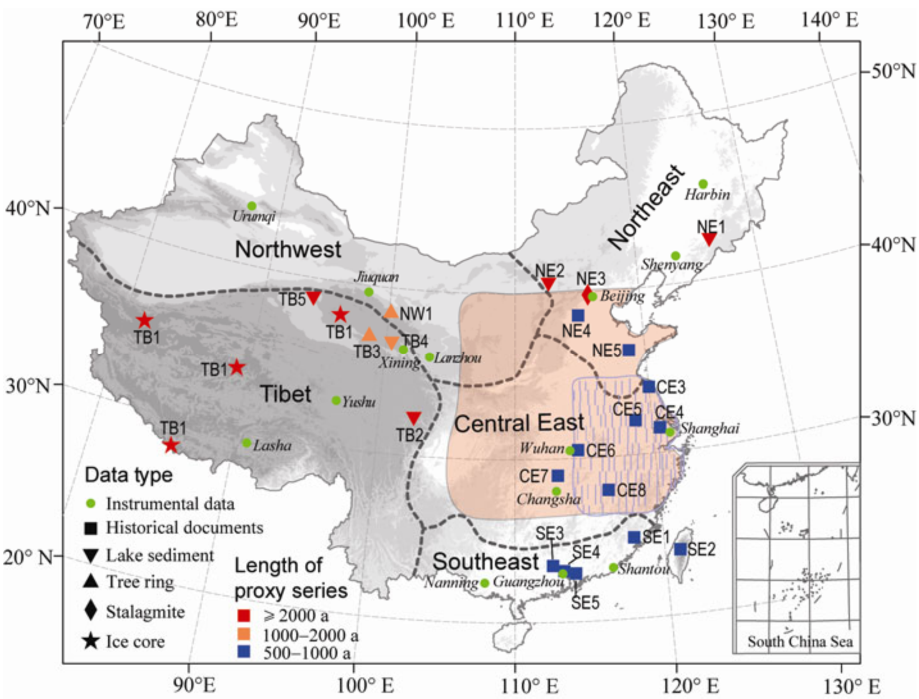

Figure 1 Regional division of temperature change in China and locations of the proxy temperature series (with proxy types marked by symbols and lengths marked by colors), and the instrumental observations used in this study. The red area (CE1) was studied by Ge et al. [10], while the pale red area with vertical lines (CE2) was studied by Wang and Wang [11]. Detailed information of the proxy temperature series is presented in Table 1. The five climate regimes were established through factor analysis of instrumental temperature data (see Ge et al. [25] for details). The light-to-dark shading indicates the elevation from low to high.

To compare the reconstruction series, each individual series was standardized using the common reconstructed reference period within that region: 1470s–1950s for NE, 1500s–1940s for CE and SE, 1060s–1990s for NW and 1050s–1990s for TB. In addition, temperature anomalies were adjusted using the standard deviation units of the

Table 1 Proxy temperature series used in this study

Proxy type [a]	Sample locations	Proxy indicator & its climatology interpretation	Initial-end year	Temporal resolution (a)	Reference	Series ID in Figure 1 [b]
Northeast (NE, 5 series)						
SD	Jinchuan Peatland (42.33°N, 126.37°E)	δ^{18}O‰, annual average temperature	3965 BC –AD 1950	10–100	[20]	NE1
SD	Daihai Basin (40.57°N, 112.68°E)	Pollen, average temperature in July	9748 BC –AD 1950	18–42	[21]	NE2
ST	Shihua cave (39.80°N, 115.80°E)	Stalagmite microlayer thickness, May–August temperature	665 BC– AD 1985	1	[18]	NE3
HD	North China (40.00°N, 118.00°E)	Cold/warm description, annual temperature	1380s–1990s	10	[8]	NE4
HD	Shandong Province (36.63°N, 117.00°E)	Cold/warm years counts for every ten years, winter temperature	1470s–1980s	10	[9]	NE5
Central East (CE, 8 series)						
HD	East China (25°–40°N, east of 105°E)	Phenophase, winter-half-year temperature	1–2000	10–30	[10]	CE1
HD	East China (25–35°N, 115–120°E)	Winter cold index, winter temperature	1470s–1970s	10	[11]	CE2
HD	East China region (34.00°N, 120.00°E)	Cold/warm descriptions, annual temperature	1380s–1990s	10	[8]	CE3
HD	Taihu Lake (31.50°N, 120.50°E)	Severe/cold/hot/warm winter years count, winter temperature	1380s–1970s	10	[12]	CE4
HD	Lower reaches of the Yangtze River (32.10°N, 118.80°E)	Winter temperature index, winter temperature	1470s–1960s	10	[13]	CE5
HD	Middle reaches of the Yangtze River (30.50°N, 114.50°E)	Same as above	1470s–1960s	10	[13]	CE6
HD	Central China (29.00°N, 113.00°E)	Cold/warm descriptions, annual temperature	1470s–1990s	10	[8]	CE7
HD	Hunan Province and Jiangxi Province (28.00°N, 116.50°E)	Winter temperature index, winter temperature	1470s–1960s	10	[13]	CE8
Southeast (SE, 5 series)						
HD	Zhejiang Province and Fujian Province (25.00°N, 118.00°E)	Winter temperature index, winter temperature	1470s–1960s	10	[13]	SE1
HD	Fujian province and Taiwan Province (24.00°N, 121.00°E)	Cold/warm description, annual temperature	1500s–1990s	10	[8]	SE2
HD	Guangdong Province and Guangxi Zhuang Autonomous Region (23.50°N, 112.50°E)	Winter temperature index, winter temperature	1470s–1960s	10	[13]	SE3
HD	Guangdong Province (23.16°N, 113.23°E)	Cold winter record pieces in every ten years, winter temperature	1400s–1940s	10	[14]	SE4
HD	South China (23.00°N, 114.00°E)	Cold/warm description, annual temperature	1500s–1990s	10	[8]	SE5
Tibet (TB, 5 series)						
IC	Composite of Dasuopu, Dunde, Guliya and Puruogangri ice cores	δ^{18}O‰, annual temperature	1–2000	10	[19]	TB1
SD	Hongyuan Peatland (32.77°N, 102.50°E)	δ^{18}O‰, annual temperature	4170 BC– AD1950	30	[22]	TB2
TR	Wulan, Qinghai Province (37.05°N, 98.67°E)	Qilian Juniper Ring-width, September-April temperature	1000–2004	1	[16]	TB3
SD	Qinghai Lake (36.60°N, 100.50°E)	Total Organic Carbon (TOC), annual temperature	1050–2000	20	[23]	TB4
SD	Sugan Lake (38.85°N, 93.90°E)	δ^{13}C‰, winter-half-year temperature	1–2000	9–11, 42	[24]	TB5
Northwest (NW, 1 series)						
TR	Central part of Qilian Mountain (north face) (38.43°N, 99.93°E)	Qilian Juniper ring-width, December-April temperature	1066-1999	3	[17]	NW1

a) SD, Sediments; ST, stalagmites; HD, historical documents; TR, tree rings; IC, ice cores; b) series IDs are the same as in Figure 1; the IDs consist of location and series number.

Table 2 Variance of the annual temperature explained by the seasonal temperatures in the instrumental period

Region	Proxy series ID	Nearest reference meteorological sites	Reference season	Variance explanation to annual temperature (%)
NE	NE3	Beijing (116°28′E, 39°48′N)	May–August	58
	NE2	Hohhot (111°41′E, 40°49′N)	July	44
	NE5	Jinan (119°59′E, 36°41′N)	Winter	86
CE (Because the series covered large areas, we selected 4 stations from this region.)	All series	Changsha (113°05′E, 28°12′N)	Winter	76
		Hangzhou (120°10′E, 30°14′N)		85
		Nanjing (118°48′E, 32°00′N)		85
		Wuhan (114°08′E, 30°37′N)		90
SE (same as above)	All series	Xiamen (118°04′E, 24°29′N)	Winter	85
		Guangzhou (113°20′E, 23°10′N)		88
		Shaoguan (113°36′E, 24°41′N)		85
		Guilin (110°18′E, 25°19′N)		90
TB	TB5	Lenghu (93°20′E, 38°45′N)	Winter	77
	TB3	Dulan (98°06′E, 36°18′N)	September–April	88
NW	NW1	Zhangye (100°26′E, 38°56′N)	December–April	81

regional instrumental data to obtain the relationship between the standard deviation and actual observed temperature; i.e. 1 standard deviation unit is 0.64°C for NE, 0.41°C for CE, 0.42°C for SE, 0.68°C for NW and 0.44°C for TB. Using these proxy temperature series, Ge et al. [25] analyzed the uncertainties in the 23 regional temperature series and reconstructed the "regional coherent temperature series" (i.e. the series with the most confidence) for each region. Correlation analysis shows that these regional coherent temperature series are highly correlated with instrumental measurements (mean of three sites with longer observation data for each region) with correlation coefficients of 0.60 (NE), 0.76 (CE), 0.44 (SE), 0.97 (TB) and 0.51 (NW).

To analyze the rates of temperature change at decadal to centennial scales, the first-order difference for each regional coherent temperature series, the running series of the difference between two adjacent 30-year periods, and the moving 100-year linear trend series (obtained using the least-squares method) were calculated. Moreover, the same calculations were carried out for each of the 24 proxy temperature series, and then, the mean and standard variation of all the rate series were calculated to analyze the rates of temperature change for the whole of China (Figures 2–4). The running series of the first-order difference (R_{10i}), the difference between two adjacent 30-year periods (R_{30i}) and the moving 100-year linear trend series (R_{100i}) were calculated using

$$R_{10i} = T_i - T_{i-1}, \tag{1}$$

$$R_{30i} = \frac{1}{3}\sum_{k=i}^{i+2} T_k - \frac{1}{3}\sum_{k=i-3}^{i-1} T_k, \tag{2}$$

$$R_{100i} = \frac{\sum_{k=i-4}^{i+5}\left(T_k \times k\right) - \frac{1}{10}\left(\sum_{k=i-4}^{i+5} T_k \times \sum_{k=i-4}^{i+5} k\right)}{\sum_{k=i-4}^{i+5} k^2 - \frac{1}{10}\left(\sum_{k=i-4}^{i+5} k\right)^2} \times 100, \tag{3}$$

where T_i denotes the normalized proxy temperature value; i denotes time, with i = 0, 1, 2, …, 199 representing the 0s, 10s, …, 1990s respectively; $1 \leqslant i \leqslant 199$ for eq. (1), $3 \leqslant i \leqslant 197$ for eq. (2) and $4 \leqslant i \leqslant 194$ for eq. (3).

2 Results

2.1 Rates of temperature change at the 100-year scale

The moving 100-year linear trend series in each region (Figure 2) shows that the latest and most rapid warming period was in the mid-19th to 20th century, which corresponds to the period from the Little Ice Age (LIA) to the 20th century. In this warming period, the peak rate for each region was no less than approximately 1.0°C/100 a; they were 1.3°C/100 a for NE, 1.1°C/100 a for CE and SE, 1.3°C/100 a for NW and 1.0°C/100 a for TB. Moreover, the exact timing and duration of the peak rate varied from region to region. Peak rates were found in the 1810s–1900s and 1850s–1940s for NE, the 1860s–1950s for CE, the 1850s–1940s for SE, and the 1820s–1910s for NW and TB. On the whole, the mean of all moving 100-year linear trend series indicates that the warming from the LIA to the 20th century started in the 1810s and had a peak warming rate of 1.1±1.2°C/100 a (interval at the 95% confidence level, which is used in the remainder of the paper) approximately during the 1850s–1940s. Although the warming rate during the 20th century (i.e. 1900s–1990s) for the whole of China reached 0.6±1.6°C/100 a, it was notably lower than the peak warming rate from the LIA to the 20th century.

Comparing with other notable warming periods during the last 2000 years, the peak rate for each region in the mid-19th to 20th century was higher than or comparable to most of the previous peaks. Nevertheless, there might have been a rapid warming period in NE during the 180s–350s with a peak rate higher than that in the mid-19th to 20th century. Additionally, the peak rate for TB during warming periods in the 260s–410s and 500s–660s might also be greater than that around the 1860s. A recent study [25] concluded that the regional coherent temperature series contains large uncertainties before the 1500s. In addition, the mean and uncertainty of all series show that the peak

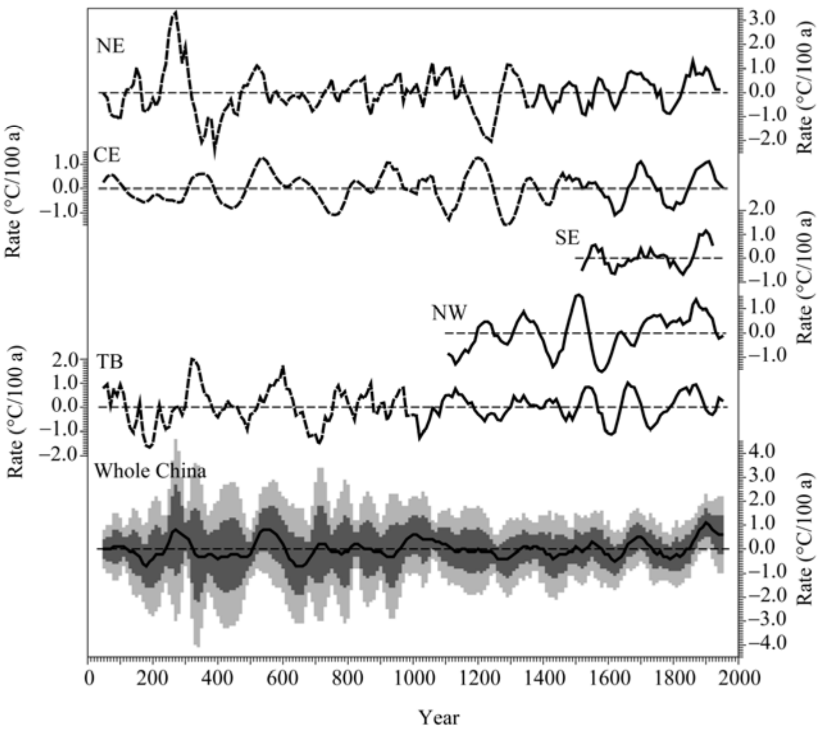

Figure 2 Rates of temperature change at the 100-year scale during the past 2000 years. For NE, CE, SE, TB and NW, the periods with relatively low confidence are marked with thick dashed black lines. For the whole-China mean, the dark shading represents an interval of ±1 standard variation, while the light shading represents an interval of ±2 standard variations.

warming rate from the LIA to the 20th century was the highest for the last 2000 years and the range of uncertainty before AD 1000 was clearly greater than that afterward. These results suggest that the rate of the regional warming trend from the mid-19th to 20th century was the greatest over the last 500 years, but it might not be the greatest for the last 2000 years in China.

On the other hand, during the last 500 years, there were rapid cooling periods around the 1790s and 1610s, with the greatest 100-year cooling rates of –0.4±1.0°C/100 a and –0.5±1.2°C/100 a respectively for the whole of China. Before AD 1500, the greatest 100-year cooling rate was –0.7°C/100 a in the 600s–690s and 130s–220s with 95% confidence intervals of –0.7±2.4°C/100 a and –0.7±1.8°C/100 a respectively. The second-greatest cooling trend was –0.4±1.2°C/100 a from the 1220s to 1310s, which might correspond to the climatic transition from the Medieval Warm Period to the LIA.

We found that the magnitude and duration of the greatest 100-year cooling trend also varied from region to region during the last 2000 years. In NE, there were two rapid cooling periods in the 300s–430s and 1170s–1280s, with both 100-year cooling rates reaching –2.0°C/100 a. However, the greatest 100-year cooling trend rate was only –0.9°C/100 a during the last 500 years in NE. In CE, the most rapid cooling period was in the 1240s–1330s with a rate of −1.5°C/100 a, while in other rapid cooling periods, such as the 700s–810s, 1050s–1150s and 1570s–1660s, the greatest 100-year cooling rates all exceeded −1.0°C/100 a. In SE, the greatest 100-year cooling rate during the last 500 years was approximately –0.7°C/100 a in the 1570s– 1660s and 1780s–1860s. In NW, rapid cooling in the last 1000 years occurred around the 1130s, 1430s and 1580s, with cooling rates of −1.3°C/100 a in the 1080s–1170s, −1.4°C/100 a in the 1380s–1470s and −1.6°C/100 a in the 1530s–1620s. In TB, there were five rapid cooling periods with rates of −1.7°C/100 a in the 140s–230s, −1.5°C/ 100 a in the 660s–750s, −1.5°C/100 a in the 970s–1060s, −1.1°C/100 a in the 1560s–1650s and −1.0°C/100 a in the 1680s–1770s.

2.2 Rates of temperature change at the 30-year scale

Figure 3 illustrates the running series of the difference between two adjacent 30-year mean temperatures. The figure suggests that the peak of warming between two adjacent 30-year periods during the 20th century was dwarfed by the warming peaks before the 20th century for NE, CE, SE and NW. Only in TB did the warming between two adjacent 30-year periods during the 20th century (i.e. from the 1940s–1960s to 1970s–1990s) reached 1.2°C/30 a, which could be comparable to the previous warming peaks. Again, the exact timing and magnitude of the 30-year warming peaks varied from region to region. We also found that the peak warming between two adjacent 30-year periods during

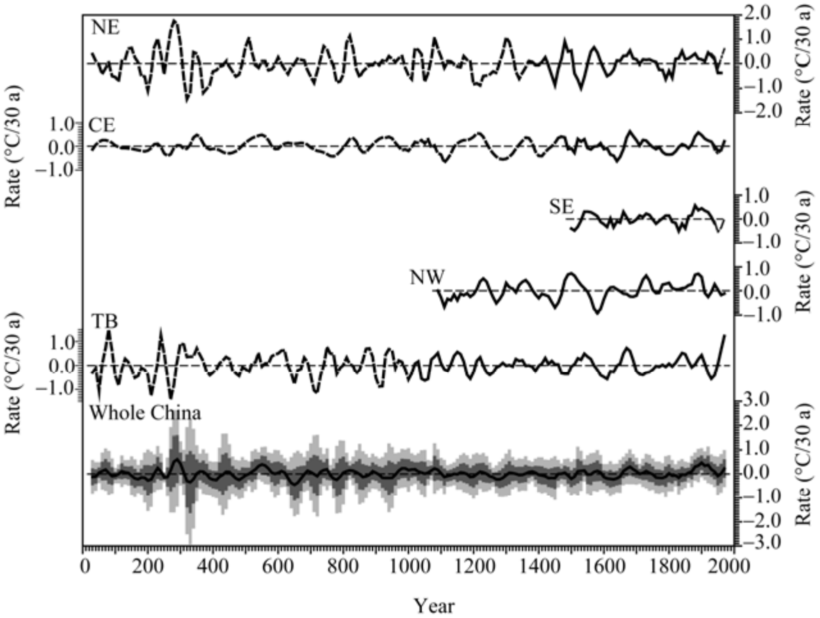

Figure 3 Same as in Figure 2, but for the 30-year scale. The rates obtained from the instrumental data are plotted as gray dot-dashed lines.

the industrial period (i.e. since the 1750s) was not unprecedented in the last 2000 years. The mean and uncertainty of all rate series at the 30-year scale within China showed warming peaks of 0.5±0.6°C/30 a (from the 1870s–1890s to 1900s–1920s) since 1750 and 0.2±0.7°C/30 a (from the 1940s–1960s to 1970s–1990s) in the 20th century; however, during the past 2000 years, the maximal rate of the 30-year warming reached 0.6±2.0°C/30 a from the 260s–280s to 290s–310s.

Meanwhile, similar characteristics were found for cooling between two adjacent 30-year periods. The rate of the most rapid 30-year cooling before the 20th century was higher than that during the 20th century in all regions. Although there was frequent rapid 30-year cooling in the LIA, the rate of the most rapid cooling between two adjacent 30-year during the LIA was less than that before the LIA. The mean of all rate series at the 30-year scale within China shows that the most notable cooling in the LIA occurred from the 1600s–1620s to 1630s–1650s with a rate of –0.2± 0.6°C/30 a. However, the rates of cooling from the 170s–190s to 200s–220s, from the 300s–320s to 330s–350s and from the 620s–640s to 650s–670s were –0.3±1.3°C/30 a, –0.3±2.5°C/30 a and –0.5±1.3°C/30 a, respectively. These results imply that the rates of temperature change at the 30-year scale during the LIA and the 20th century were not unprecedented.

2.3 Rates of temperature change at the 10-year scale

Because the majority of the original proxy temperature series have a resolution coarser than 10 years before AD 1450, we only examined the rates of temperature change at the 10-year scale for the period after AD 1450. Figure 4 shows the first-order difference for each regional coherent temperature series and the mean of all rate series within China for the past 500 years. It is found that there was rapid decadal warming in the late 20th century in each region. The mean of all rate series indicates that the rate of warming from the 1980s to 1990s was 0.5± 0.5°C/10 a for the whole of China, which was the most rapid decadal warming during the past 500 years. On a regional scale, however, the peak decadal warming rate for the 20th century was 0.5°C/10 a (1970s to 1980s) in NE, 0.7°C/10 a (1980s to 1990s) in CE, 0.7°C/10 a (1970s–1980s) in TB, and 0.4°C/10 a (1980s to

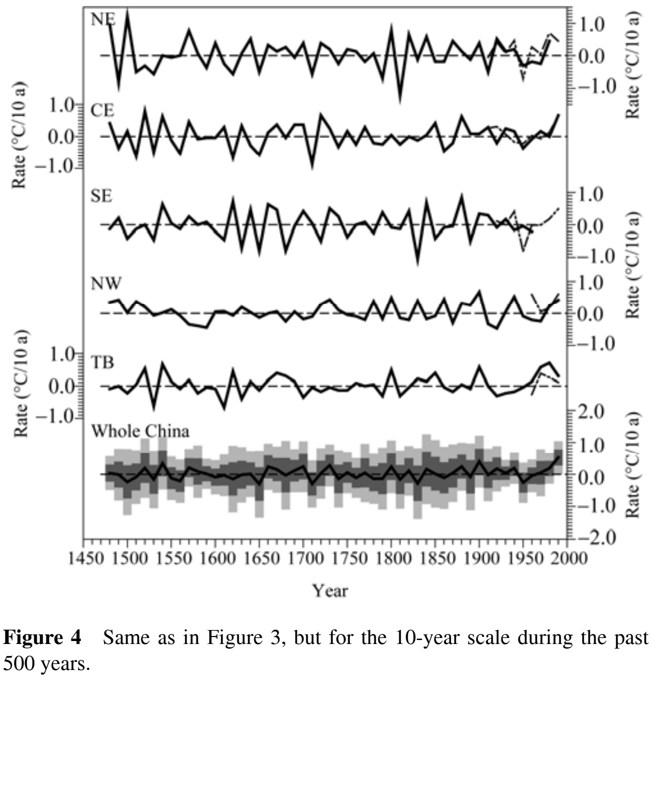

Figure 4 Same as in Figure 3, but for the 10-year scale during the past 500 years.

1990s) in NW. These peaks are only comparable to previous decadal warming peaks. Because proxy data are unavailable after the 1970s for SE, it is difficult to compare the peak rate of decadal warming in the late 20th century to previous peak rates in that region. The available observational data indicate that the peak rate of decadal warming in the 20th century was only 0.6°C/10 a (1980s to 1990) in SE, which was less than that during the past 500 years. These results suggest that warming at the decadal scale in the late 20th century was particularly notable, but it might not be unusual in the context of warming in the past 500 years.

On the other hand, the mean of all rate series shows that the most rapid decadal cooling was from the 1940s to 1950s at a rate of –0.3±0.6°C/10 a, which is similar to rates before the 20th century. Additionally, the rate of most rapid cooling in the 20th century for each region was less than earlier rates.

3 Discussion and conclusion

By analyzing 24 series of temperature reconstructions from multi-proxy data for regions in China, we examined the rates of temperature change at the centennial and decadal scales in China. It was discovered that the exact timing, duration and magnitude of the maximal centennial warming rates varied from region to region. The most rapid warming occurred from the 180s to 350s in NE, and from the 260s to 410s and from the 500s to 660s in TB, while the peak warming rate for the whole of China reached 1.1±1.2°C/100 a in the period from the LIA to the 20th century, which was the highest rate over the past 500 years and possibly the past 2000 years. The whole-China mean rate of the most rapid cooling during the LIA, however, was still less than those during the 600s–690s and 130s–220s. At the 30-year scale, the peak rate of warming in the 20th century was less than previous rates, such as that for the rapid warming from the LIA to the 20th century and from the 270s–290s to 300s–320s. Although there was frequent rapid 30-year cooling in the LIA, the rate of the most rapid 30-year cooling during the LIA was not unprecedented. The decadal warming rate in the late 20th century was particularly evident, but it might not be unusual in the context of warming in the past 500 years. In conclusion, the warming rates at centennial and decadal scales in the 20th century were not exceptional for the past 2000 years. It is demonstrated that although human-induced greenhouse effects may have contributed to rapid global warming in the 20th century, in the case of China, such rapid decadal to centennial warming has occurred in preindustrial times.

It should be noted that the proxy-based temperature series contain uncertainties, particularly for the period before AD 1500 [25]. Therefore, it is worthwhile discussing differences in the rates of temperature changes between the proxy-based and instrumental records. In China, instrumental temperature records have existed, although sparsely distributed, since the early 20th century, and have been analyzed by Ge et al. [25]. Using these observational data, we calculated and plotted the rates of temperature change for each region at 30-year and 10-year scales in the 20th century in Figures 3 and 4. The results derived from the instrumental data show that, at the 30-year scale, the rate of most rapid warming in NE was 0.6°C/30 a from the 1940s–1960s to 1970s–1990s and the second most rapid was 0.4°C/30 a from the 1900s–1920s to 1930s–1950s, while the rate of most rapid cooling was –0.2°C/30 a from the 1920s–1940s to 1950s–1970s. There was discrepancy between the proxy and instrumental data in terms of the rates of temperature change from the 1930s–1950s to 1960s–1980s and afterward owing to a lack of proxy data for the 1990s (i.e. cooling was found in the proxy data but warming was found in the instrumental data). However, the maximal warming rate derived from the instrumental data (i.e. 0.6°C/30 a warming from the 1940s–1960s to 1970s–1990s) is still less than the previous peak rates represented by the proxy series. In the case of CE, there is little difference between the rates derived from the proxy and instrumental data. In the case of SE, although no proxy data are available for comparing the rates after the 1970s, the instrumental data show rapid cooling from the 1920s–1940s to 1950s–1970s but no notable warming during the 20th century, which is consistent with the results derived from the proxy data.

At the 10-year scale, the instrumental data show that all the regions experienced rapid warming in the late 20th century, which is similar to the changes derived from the proxy data. However, the exact rates of warming between the proxy and instrumental data could not be compared point by point. This is mainly because the proxy data contain uncertainties when used for short time spans. For example, the proxy data derived from lake sediment, peatland and ice cores may contain dating errors, and no proxy data can reveal the full spectrum of temperature variations completely. Moreover, the discrepancies between proxy and instrumental data may be also attributed to the low spatial density of the proxy data, especially for long proxy series. Especially, in the case of NE, two of five proxy series were derived from peatland and lake sediment and thus had coarse temporal resolution and larger dating errors; in the case of NW, there is only one series. Therefore, the assessments for these two regions have large uncertainties, which require future investigation.

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