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Climate of the Past

Winter temperature variations over the middle and lower reaches of the Yangtze River since 1736 AD

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Abstract. We present statistically reconstructed mean annual winter (December–February) temperatures from the middle and lower reaches of the Yangtze River (24° N–34° N, 108° E–123° E within mainland China) extending back to 1736. The reconstructions are based on information regarding snowfall days from historical documents of the Yu-Xue-Fen-Cun archive recorded during the Qing Dynasty (1644–1911). This information is calibrated with regional winter temperature series spanning the period from 1951 to 2007. The gap from 1912 to 1950 is filled using early instrumental observations. With the reference period of 1951–2007, the 18th century was 0.76 °C colder, and the 19th century was 1.18 °C colder. However, since the 20th century, the climate has been in a warming phase, particularly in the last 30 yr, and the mean temperature from 1981 to 2007 was 0.25 °C higher than that of the reference period of 1951–2007, representing the highest temperatures of the past 300 yr. Uncertainty existed for the period prior to 1900, and possible causes of this uncertainty, such as physical processes involved in the interaction between temperature and snowfall days and changing of observers, are discussed herein.

1 Introduction

Present and future paleoclimate research will focus more on regional climatic and environmental responses to global or hemispheric changes, and increasing spatial coverage of individual datasets will be a major step toward a more appropriate data basis (PAGES, 2009). The US National Research Council (2006) called for additional regional precipitation and temperature data to be obtained, which would help to reduce the uncertainties associated with current reconstructions. Sub-continental seasonal temperature reconstruction is important to detect the influence of climate forcings at regional or local scales (Hegerl et al., 2011).

Temperature reconstruction for Middle and Lower Reaches of the Yangtze River (MLRYR, 24° N–34° N, 108° E–123° E within mainland China) is of great relevance for at least two reasons. First, winter temperatures in the MLRYR region are closely correlated with precipitation, but less variance in winter temperature is explained by snowfall days in the most northerly and the most southerly areas of this region (Zhou et al., 1994); second, the greatest variability in the minimum temperature during the winter occurred in the MLRYR based on the observed data from 1952 to 1995 (Zhai et al., 1999).

Although multi-proxies, including historical documents, tree-rings, ice cores and sediments, can be used for temperature reconstruction, the advantage of documents is that they provide high-resolution climate information for Eastern China, while the spatial distribution for most of other proxies is restricted to Western China (Ge et al., 2010; Shao et al., 2010). Ge et al. (2003) reconstructed winter half-year temperature series for the MLRYR during the past 2000 yr using phenological cold/warm data, although with a rather low time resolution (from 10 to 30 yr). Outside of China, many great reconstructions extending back 500–1000 yr using historical documents have been developed during the past few decades. For example, in Japan, summer and winter temperature variations were reconstructed from several historical sources, which included cherry-tree flowering date records, lake freezing date records and weather diary records (Mikami, 2008). The state of the art for historical climatology in Europe and the Mediterranean region was comprehensively reviewed by Brázdil et al. (2005, 2010) and Luterbacher et al. (2006, 2012), and seasonal temperatures with a high resolution in key climatic periods, i.e., the Medieval Warm Anomaly and Little Ice Age, were reconstructed using information obtained from narrative sources, dairies and (bio)physical data (dates of river and harbour freezing, cereal and grape harvests), among other sources (e.g., Pfister, 1992; Luterbacher et al., 2004; Xoplaki et al., 2005; Dobrovolný et al., 2010; Leijonhufvud et al., 2010; Možný et al., 2012).

Here, we present new evidence regarding the number of snowfall days obtained from Chinese historical documents from the Yu-Xue-Fen-Cun archive as well as the connection to seasonal mean winter temperatures (from December to the next February) and a statistical reconstruction associated with the uncertainties in the annual winter temperature during the past 300 yr over the MLRYR. This study will provide a basic dataset for analysing the inter-annual to inter-decadal variability of temperature changes at the regional scale and evaluate the warming rate since the industrial revolution.

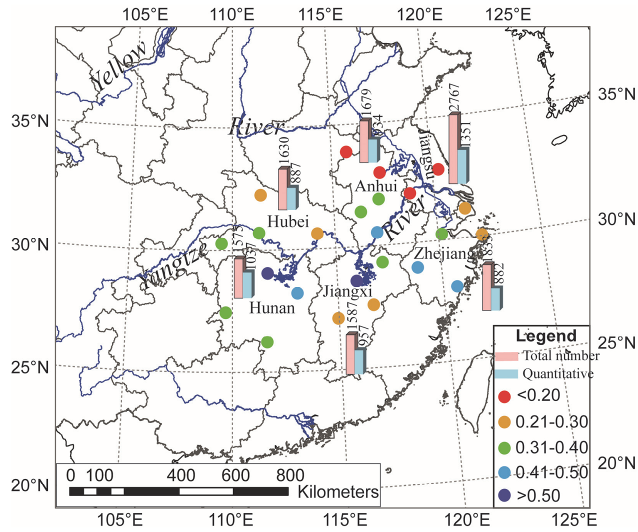

Fig. 1. Locations of stations (dots) used to reconstruct regional winter temperature in this study; the bars indicate the numbers of total records and quantitative records; and the colour of the dots indicates the variance in snowfall days explained by the winter temperature.

2 Data sources

We choose 24 stations covering Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei and Hunan provinces in the MLRYR region (Fig. 1) for which data are available in both historical and instrumental periods to reconstruct winter temperature changes during the past 300 yr. Two types of datasets are used in this study: meteorological observational data and data from Chinese historical documents from Eastern China at the Yu-Xue-Fen-Cun archive.

2.1 Meteorological data

China monthly surface climate data from 1951 to 2007 are published every year by the Chinese Meteorological Administration (CMA). We extracted daily weather information including snow, rain or sleet and total precipitation at the 24 studied stations (Fig. 1). To obtain the regional winter (December to February) mean temperature over the MLRYR, we downloaded monthly mean temperature data for 122 stations from the CMA website (http://cdc.cma.gov.cn/) and averaged them, including data from the above-mentioned 24 stations. The information from the stations from 1996 to 1998 is unavailable due to a short observational parameter adjustment.

Meteorological data are available for only a few stations prior to 1951. To maintain the continuity of the long-term series, we chose five stations, at Shanghai, Wuhan, Hangzhou, Nanjing and Changsha, from long-term instrumental climatic datasets published by the Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory (available at: http://dss.ucar.edu/datasets/ds578.5/) to reconstruct regional temperature change during the period 1906–1950. This dataset was also derived from instrumental measurements, and quality assurance checks were performed, including examining the data for completeness, reasonableness and accuracy. Based on the description of this dataset, few station records can be considered truly homogeneous. Even the best stations were subjected to minor relocations or changes in observation times, and many have undoubtedly experienced large increases in urbanization. Fortunately, station histories are available to assist in proper interpretation of trends or jumps in the data. Thus, relative homogeneity of stations used was not tested. The five stations present very good spatial representativeness for the MLRYR region and capture 50–90 % of the variance in the regional winter mean temperatures from 1951 to 2007 based on linear regression analysis. However, the measurements at most stations, excluding Shanghai, from 1937 to 1945 were missing due to the persistent wars. The missing data for each station are filled with the interpolation values calculated from linear regression models showing the highest correlation coefficients between one station and its neighbouring station based on observations for the period 1951–2007.

2.2 Yu-Xue-Fen-Cun archive

The Yu (rainfall)-Xue (snowfall)-Fen (Chinese length unit of 0.32 cm, although the scale varied in from the early period of the Qing Dynasty to the present)-Cun (3.2 cm) records are a kind of memos-to-emperor produced by governmental officers during the Qing Dynasty from 1644 to 1911 recording rain infiltration depth measurements from the dry-wet soil boundary layer to the ground surface obtained by digging into the soil with the shovel after rainfall, as well as the snow

Table 1. Yu-Xue-Fen-Cun information for the MLRYR.

Provinces	Periods	Years without data
Hubei	1736–1851	1751, 1783, 1788, 1798, 1817, 1819, 1837–1838, 1845
Hunan	1736–1909	1741, 1751, 1778, 1801, 1805, 1808, 1819, 1834, 1837–1838, 1845–1846, 1859, 1863, 1870, 1872–1873, 1881, 1883–1884, 1906
Anhui	1736–1852	1751, 1773, 1783, 1801, 1819, 1838, 1845
Jiangxi	1736–1907	1739, 1741, 1751–1752, 1758, 1761, 1771, 1778, 1783, 1798, 1801, 1819, 1832–1833, 1837–1838, 1845–1846, 1859, 1863, 1870, 1881, 1883
Jiangsu	1736–1846	1751, 1778, 1801, 1819, 1832–1834, 1838, 1845
Zhejiang	1736–1857	1749, 1751, 1778, 1819, 1837–1838, 1844–1845

depth on the surface after snowfall for each precipitation event, at 273 administrative sites over the whole of China. The Yu-Xue-Fen-Cun archive applied a fixed report format, in which measurements were performed at a fixed site by a fixed observer, so it is a systematic and homogeneous archive (Ge et al., 2005). The reliability and accuracy of these historical documents have been discussed in the previous studies (Ge et al., 2005; Wang et al., 2008).

The Yu-Xue-Fen-Cun archive over the MLRYR includes quantitative and qualitative winter weather information (Fig. 1), with the quantitative records occupying over 50 %, approximately 8 pieces of records for each winter in one province. In addition, due to fire, theft and wars, the records are missing for several years, representing 8 % of all years from 1736 to 1852. Only 8 stations in Hunan and Jiangxi provinces (Nanchang, Jingdezhen, Nancheng and Jian in Jiangxi province and Changsha, Changde, Lingling and Zhijiang in Hunan province) were involved, for which fine weather archives are available from 1853 to 1905 and 10 % of the total years are missing (see Table 1 for details). Although we presented some examples of these historical documents in previous publications (Ge et al., 2005; Wang et al., 2008), two specific records for winter are given here to show how these data were documented during the Qing Dynasty. A quantitative example is "Jiangning (today Nanjing city) received snowfall from YouShi (Chinese ancient time, 05:00 p.m.–07:00 p.m.) on the 28th day of the twelfth month on the third year of the Qianlong Reign to MaoShi (05:00–07:00 a.m.) on the 1st day of the first month on the fourth year of the Qianlong Reign in the lunar calendar (6–8 February 1739 in Gregorian calendar), and the snow depth on the ground surface reached up to 6-Cun (19.2 cm)", as reported by Li, Ying who was in charge of silk manufacturing in Jiangning city. From this record, information on the location, date, duration of snowfall and snow depth can be obtained. Then, we count the number of snow days (3 days in this example) from each record and calculate the total number for the whole winter. Because different governmental officers could report the same snowfall information at the same location, any repeat snow records should be deleted. An example of a qualitative record is "As reported by Wang, Youling, General Governor of Zhejiang province, Hangzhou was under sunshine at the beginning of the 11th month in the tenth year of the Xianfeng Reign (12–21 December 1860) and received snowfall during the middle and last ten days of the 11th month (22 December 1860–10 January 1861); then, several snow events occurred in the 12th month (11 January 1861–9 February 1861)". These records provide general weather information during the winter and allow cross-checking.

3 Methodology

We first test the relationship between the winter temperature and the number of snowfall days based on the meteorological data from the 24 individual stations from 1951 to 2007, then apply a Partial Least Squares (PLS) statistical regression model extending back to 1736 AD.

3.1 Relationship between the winter temperature and snowfall days at each station

Small snowfall events with total precipitation of less than 1 mm, such as those involving very small sleet and granular snow, can usually be measured with a meteorological instrument, but the Yu-Xue-Fen-Cun archive only recorded those events that could be observed visually by people. Thus, before calculating the snowfall days during the observational periods, we extract those snowfall events with a total precipitation of greater than 1 mm to maintain the consistency between the historical and observational periods. The mean winter (December–February) temperatures show a significant ($\alpha = 0.01$ significance level, sample number $\geq$47, see Table 2) correlation, ranging from 0.41 to 0.75 with snowfall days at each of the 24 stations covering the period from 1951 to 2007.

3.2 Regional temperature reconstruction

We first divided the entire time series into three periods on basis of the available data to reconstruct temperature during historical times, with the three periods including different stations, i.e., all 24 stations for the period from 1736–1852, 8 stations for the period from 1853–1905, and 5 stations for the period from 1906–1950. The observed regional mean winter temperature at 122 stations from 1951 to 2007 was used for calibration and verification. Snowfall days-winter temperature transfer functions for the two periods from 1736–1852 and 1853–1905 were developed using a PLS regression model (Höskuldsson, 1988; Shen et al., 2006) with MINITAB software. Verification of our reconstruction was undertaken using the leave-one-out cross-validation method (Michaelsen, 1987). The winter mean temperature time series from 1736 to 1852 and from 1853 to 1905 is, therefore, reconstructed based on the optimal model with the highest predicted R^2 value, and the statistics used in the verification procedure are listed in Table 3. The predictors are the numbers of snowfall days at the 24 stations from 1736 to 1852 and at 8 stations from 1853 to 1905, and the predictands are the mean regional temperature values. The variance in the winter mean temperature explained by the selected model (component in Table 3) is 67 % for 1736 to 1852 and 54 % for 1853 to 1905.

Observed temperature data from 1906 to 1950 are only available at Shanghai, Wuhan, Hangzhou, Nanjing and Changsha in the MLRYR region. The transfer function between the winter temperature at an individual station and the regional winter temperature is implemented via the PLS statistical method. The variance in the mean temperature explained by the selected model is 98 %. The full series was generated by combining the reconstructions for the different periods. Because the reconstruction of regional series was produced from different subperiods, the mean value for 1853–1905 from 8 stations had to be adjusted to the level of reconstruction from the 24 stations. For example, we use 8 stations and reconstruct the regional temperature for 1853–1905. To combine the different sub-periods, these 8 stations are also used to reconstruct the temperature for 1736–1852, and we then calculate the mean value of this reconstruction series. Next, the difference for the period 1736–1852 between the results from the 8 stations and 24 stations is compared. If the latter value is higher (lower) than the former, then we subtract (add) the value of this difference from (to) our reconstruction during the period 1853–1905.

4 Results

Figure 2 shows the reconstructed mean winter temperature anomaly and its 95 % confidence interval for the past 300 yr with an annual resolution as well as a comparison between the reconstructed and observed winter temperatures for 1951–2007. It is worth noting that the mean temperature of the reference period from 1951 to 2007 is 5.25 °C averaged over 122 stations in the MLRYR. The characteristics of the mean winter temperature changes over the past 300 yr can be highlighted as follows. In the 18th century, the climate is relatively cold, with a mean temperature of −0.76 °C, and no obvious trend existed. In the 19th century, the climate experienced a cooling period, with a mean temperature of −1.18 °C, including the two coldest winters of the past 300 yr, in 1865/1866 and 1809/1810, which were 4.3 °C and 3.4 °C colder than the mean temperature for 1951–2007, respectively. Since the 20th century, the climate has entered a warming period. During the last three decades, the temperature increased dramatically and the mean temperature from 1981 to 2007 was 0.25 °C higher than that of 1951–2007, which reached the highest level of the past 300 yr. Considering the whole time series, the temperature difference between the mildest (2000/2001) and coldest (1865/1866) winter is 5.6 °C. On a decadal time scale, the coldest decade was the 1860s and the warmest decade was experienced from 1991 to 2000. The temperature difference between the warmest and coldest decade is 4.6 °C.

Moreover, we analysed the changing trend at 30-yr and centennial time scales to determine how rapidly climate warming/cooling occurred during the past 300 yr. On a 30-yr time scale, the greatest warming was experienced over the period 1886–1915, with a rate of 0.59 °C/10 yr. The strongest cooling trend was detected between 1843 and 1872, with a rate of 0.88 °C/10 yr. At a centennial time scale, one rapid cooling trend of −0.7 °C/100 yr occurred from 1736 to 1835, and the strongest warming trend, with a rate of 1.9 °C/100 yr, was observed from 1862 to 1961. The warming rate during the 20th century, from 1901 to 2000, was 0.66 °C/100 yr. Because the 100 yr from 1862 to 1961 covered three temperature change patterns, i.e., coldest decade (in the Little Ice Age) – period of increasing temperatures – warming stage, the trend from a cold spell to a warm peak is steeper than that of the 20th century.

5 Discussion

Rather than using a single station to reconstruct regional temperature changes, our series employed weather information from multiple stations to reconstruct the mean winter temperature over the MLRYR, explaining 54–98 % of instrumental variance from 1951 to 2007, which reduced the uncertainty of the reconstruction results. However, large uncertainties still existed in our reconstruction from 1736 to 1905,

Table 2. Linear regression relationship between winter temperature changes and snowfall days for 24 stations from 1951 to 2007.

Provinces	Stations	Location (° N, ° E)	k	b_0	p	R^2	N	Period
	Shanghai	31.17, 121.43	−0.21	5.88	0.0004	0.21	54	1951–2007
Jiangsu	Dongtai	32.87, 120.32	−0.13	3.56	0.0025	0.17	52	1953–2007
	Nanjing	32.00, 118.80	−0.11	4.27	0.0016	0.18	54	1951–2007
Zhejiang	Hangzhou	30.23, 120.17	−0.16	6.34	<0.0001	0.37	54	1951–2007
	Dinghai	30.03, 122.10	−0.19	7.43	<0.0001	0.28	50	1955–2007
	Quzhou	28.97, 118.87	−0.18	7.41	<0.0001	0.49	54	1951–2007
	Wenzhou	28.03, 120.65	−0.30	9.52	<0.0001	0.43	47	1951–2007
Anhui	Anqing	30.53, 117.05	−0.21	6.31	<0.0001	0.45	54	1951–2007
	Hefei	31.87, 117.23	−0.19	5.07	<0.0001	0.39	53	1952–2007
	Huoshan	31.40, 116.32	−0.15	4.84	<0.0001	0.38	51	1954–2007
	Bangbu	32.95, 117.38	−0.17	3.93	0.001	0.19	54	1951–2007
	Bozhou	33.87, 115.77	−0.11	2.59	0.0095	0.13	52	1953–2007
Jiangxi	Nanchang	28.60, 115.92	−0.25	7.54	<0.0001	0.56	54	1951–2007
	Jingdezhen	29.30, 117.20	−0.20	7.16	<0.0001	0.35	53	1952–2007
	Nancheng	27.58, 116.65	−0.20	7.77	<0.0001	0.26	53	1952–2007
	Jian	27.12, 114.97	−0.18	8.16	0.0002	0.24	53	1951–2007
Hubei	Wuhan	30.62, 114.13	−0.17	5.87	<0.0001	0.26	54	1951–2007
	Yichang	30.70, 111.30	−0.19	7.04	<0.0001	0.40	54	1951–2007
	Enshi	30.27, 109.47	−0.18	6.74	<0.0001	0.40	53	1951–2007
	Laohekou	32.23, 111.40	−0.13	4.77	0.0002	0.24	54	1951–2007
Hunan	Changsha	28.20, 113.08	−0.18	7.16	<0.0001	0.44	54	1951–2007
	Changde	29.05, 111.68	−0.21	7.45	<0.0001	0.55	54	1951–2007
	Lingling	26.23, 111.62	−0.21	8.01	<0.0001	0.35	54	1951–2007
	Zhijiang	27.45, 109.68	−0.18	6.96	<0.0001	0.35	54	1951–2007

Note: assuming the linear regression $y = kx + b_0$, predictor (x) is snowfall days during winter (December to next February), and the dependent variable (y) is temperature in this period; all equations passed the 99 % confidence level; R^2 is explained variance, measuring the proportion of variation accounted for by a mathematical model; and N is the sample number.

Table 3. The selected PLS regression models for the winter temperatures between regions and individual stations and verifications for 1736–1852, 1853–1905 and 1906–1950 based on the leave-one-out cross-validation method.

	Component	Variance	SE	R^2	PRESS	Predicted R^2
1736–1852	1	0.51	20.68	0.60	23.20	0.5472
	2*	0.67	17.00	0.67	21.85	0.5735
	3		13.68	0.73	22.40	0.5628
	4		10.89	0.79	25.40	0.5042
	5		9.51	0.81	25.07	0.5107
1853–1905	1	0.65	27.36	0.47	30.51	0.4045
	2*	0.77	23.75	0.54	30.08	0.4128
	3		23.57	0.54	31.27	0.3897
	4		23.57	0.54	31.40	0.3871
	5		23.57	0.54	31.48	0.3856
1906–1950	1	0.88	1.80	0.97	1.91	0.9675
	2	0.96	1.55	0.97	1.73	0.9706
	3*	0.99	1.39	0.98	1.69	0.9713
	4		1.38	0.98	1.79	0.9696
	5		1.37	0.98	1.79	0.9695

* The selected model (component) used to reconstruct temperatures; SE indicates standard error; PRESS indicates prediction sum of squares.

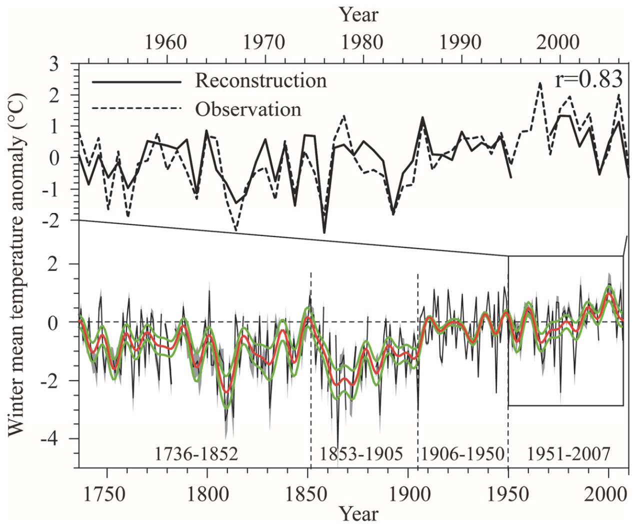

Fig. 2. Mean winter temperature anomalies from 1736 to 2007, with the 95 % confidence interval and a comparison between reconstruction and observation data from 1951 to 2007. Red line indicates the 10-yr Fast Fourier Transform low-pass filter, and the green lines are the 10-yr Fast Fourier Transform low-pass filters for the 95 % confidence intervals; base period: 1951–2007.

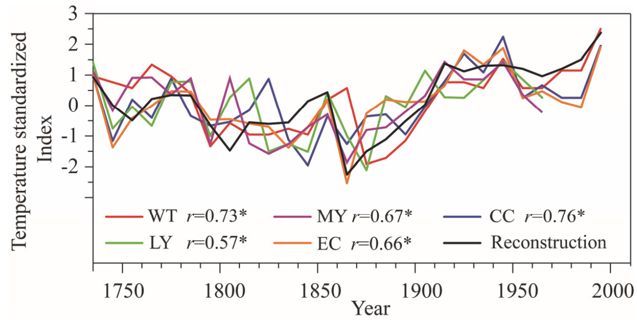

Fig. 3. Comparison between different reconstructions from historical documents and our reconstruction. Asterisk (*) indicates that the correlation coefficient between the two reconstructed series passed the $\alpha = 0.01$ significance level. EC is the winter temperature over East China (Wang and Wang, 1990); CC is the annual temperature in Central China (Wang et al., 1998); MY and LY are winter temperature indices in the Middle of the Yangtze River and Lower reaches of the Yangtze River, respectively (Zhang et al., 1980); and WT is the winter half-year temperature in Eastern China (Ge et al., 2003).

which could be due to the following reasons. First, the number of snowfall days is highly related to the winter temperature, but whether water vapour is abundant or not also plays an important role in the occurrence of snowfall, which caused uncertainty related to the unexplained variance in our statistical models. Second, limited by the original data source, the uncertainties changed over time; for example, from 1853 to 1905, fine records are only available for eight stations, which caused a lower level of confidence to exist for this period compared with the period from 1736 to 1852. Third, the format of the historical document recording system is uniform throughout the MLRYR region, but due to the life span of observers and their terms in office, the accuracy and detail of the records may vary.

Only a few winter temperature reconstructions covering the past centuries are available from different areas of China. Wang and Wang (1990) reconstructed winter temperature using a winter cold index based on descriptive on cold/warm conditions over East China (EC) centred at 34° N and 120° E. Wang et al. (1998) reconstructed annual temperatures inferred from cold/warm records in Central China (CC), geographically centred at 29° N and 113° E. Zhang et al. (1980) reconstructed winter temperature indices for the Middle of the Yangtze River (MY) and the Lower reaches of the Yangtze River (LY) based on the frequency of cold/warm years. Ge et al. (2003) determined winter half-year temperature changes in Eastern China (WT) using phenological records and related cold/warm data. For the purpose of comparison among the reconstruction series, we first average our annual reconstructions to decadal winter means. Then, each individual dataset was standardized by subtracting its long-term mean and dividing by its long-term standard deviation from the 1730s to the 1960s.

Although these reconstructions do not fully cover the same regions discussed herein and not all of the reconstructions provided quantitative winter (December–February) temperatures, we found that our reconstruction shows similarities to other published temperature reconstructions, and the correlation coefficients for the entire time series ranged from 0.57 to 0.76 (Fig. 3), surpassing the 0.01 significance level. However, if we only focus on the relationship prior to the 1900s, the coefficients ranged from 0.45 to 0.63, surpassing the 0.1 significance level, although EC (low coefficient of 0.31) was excluded. This result of comparison is consistent with the large uncertainty that existed before 1900. The six temperature series all showed a quasi-“V” shape during the past 300 yr: a relatively cold phase occurred in the 18th century, following which the climate exhibited the lowest temperature level during the 19th century and then increased continuously, reaching its highest level of the past 300 yr.

6 Conclusions

We present a new annually resolved winter mean temperature reconstruction with some uncertainty over the Middle and Lower Reaches of the Yangtze River of China during the past 300 yr using snowfall day data from the Yu-Xue-Fen-Cun archive from the Qing Dynasty. Large uncertainty existed before 1900 due to the incomplete explanation of variance in the regression models used to reconstruct the past temperature, the low accuracy of the original documents and the sparseness of stations. However, our regional reconstruction reduced the uncertainty of the results compared to using a single station. The overall pattern of winter temperature variations during the past 300 yr is shown here. The climate in the 18th century was in a relatively cold phase, with a −0.76 °C mean temperature anomaly observed (for the reference period of 1951–2007). Then, in the 19th century, the climate enters the coldest period since 1736, showing a −1.18 °C mean temperature anomaly, and this century has been recognised by most reconstructions performed for the Northern hemisphere and China as one of the coldest (Jansen et al., 2007; Ge et al., 2010). Since the 20th century, the climate has entered a warming period. In particular, the mean temperature from 1981 to 2007 was 0.25 °C higher than that of 1951–2007, which reached the highest level of the past 300 yr. The warming rate during the 20th century from 1901 to 2000 was 0.66 °C/100 yr, which is lower than that from 1862 to 1961, when the rate was 1.89 °C/100 yr. This reconstruction on a decadal time scale is highly consistent with other long-term proxy temperature series derived from Chinese historical documents (Zhang, 1980; Wang and Wang, 1990; Wang et al., 1998; Ge et al., 2003). All of the curves indicate a warmer period beginning in the 20th century and a colder period during the 19th century, which indicates that the historical documents can capture information regarding decadal temperature variations well.

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References

Brázdil, R., Pfister, C., Wanner, H., Von Storch, H., and Luterbacher, J.: Historical climatology in Europe – the state of the art, Clim. Change, 70, 363–430, 2005.

Brázdil, R., Dobrovolný, P., Luterbacher, J., Moberg, A., Pfister, C., Wheeler, D., and Zorita, E.: European climate of the past 500 years: new challenges for historical climatology, Clim. Change, 101, 7–40, 2010.

Dobrovolný, P., Moberg, A., Brázdil, R., Pfister, C., Glaser, R., Wilson, R., van Engelen, A., Limanówka, D., Kiss, A., Halíèková, M., Macková, J., Riemann, D., Luterbacher, J., and Böhm, R.: Monthly and seasonal temperature reconstructions for Central Europe derived from documentary evidence and instrumental records since AD 1500, Clim. Change, 101, 69–107, 2010.

Ge, Q.-S., Zheng, J.-Y., Fang, X.-Q., Man, Z.-M., Zhang, X.-Q., Zhang, P.-Y., and Wang, W.-C.: Winter half-year temperature reconstruction for the middle and lower reaches of the Yellow River and Yangtze River, China, during the past 2000 years, Holocene, 13, 933–940, 2003.

Ge, Q.-S., Zheng, J.-Y., Hao, Z.-X., Zhang, P.-Y., and Wang, W.-C.: Reconstruction of historical climate in China: high-resolution precipitation data from Qing dynasty archives, B. Am. Meteorol. Soc., 86, 671–679, 2005.

Ge, Q.-S., Zheng, J.-Y., Hao, Z.-X., Shao, X.-M., Wang, W.-C., and Luterbacher, J.: Temperature variation through 2000 years in China: An uncertainty analysis of reconstruction and regional difference, Geophys. Res. Lett, 37, L03703, doi:10.1029/2009GL041281, 2010.

Hegerl, G., Luterbacher, J., González-Rouco, F. J., Tett, S., Crowley, T., and Xoplaki, E.: Influence of human and natural forcing on European seasonal temperatures, Nat. Geosci., 4, 99–103, 2011.

Höskuldsson, A.: PLS regression methods, J. Chemometr., 2, 211–228, 1988.

Jansen, E., Overpeck, J., Briffa, K. R., Duplessy, J.-C., Joos, F., Masson-Delmotte, V., Olago, D., Otto-Bliesner, B., Peltier, W. R., Rahmstorf, S., Ramesh, R., Raynaud, D., Rind, D., Solomina, O., Villalba, R., and Zhang, D.: Palaeoclimate, in: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

Leijonhufvud, L., Wilson, R., Moberg, A., Söderberg, J., Retsö, D., and Söderlind, U.: Five centuries of Stockholm winter/spring temperatures reconstructed from documentary evidence and instrumental observations, Clim. Change, 101, 109–141, 2010.

Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., and Wanner, H.: European seasonal and annual temperature variability, trends and extremes since 1500, Science, 303, 1499–1503, 2004.

Luterbacher, J., Xoplaki, E., Casty, C., and 46 coauthors: Mediterranean climate variability over the last centuries: a review, in: The Mediterranean Climate: an overview of the main characteristics and issues, edited by: Lionello, P., Malanotte-Rizzoli, P., and R. Boscolo, Elsevier, Amsterdam, 27–148, 2006.

Luterbacher, J., García-Herrera, R., Allan, A. R., and 42 coauthors: A review of 2000 years of paleoclimatic evidence in the Mediterranean, in: The Climate of the Mediterranean region: from the past to the future, edited by: Lionello, P., Elsevier, Amsterdam, The Netherlands, 87–185, 2012.

Michaelsen, J.: Cross-validation in statistical climate forecast models, J. Clim. Appl. Meteorol., 26, 1589–1600, 1987.

Mikami, T.: Climatic variations in Japan reconstructed from historical documents, Weather, 63, 190–193, 2008.

Možný, M., Brázdil R., Dobrovolný, P., and Trnka, M.: Cereal harvest dates in the Czech Republic between 1501 and 2008 as a proxy for March–June temperature reconstruction, Clim. Change, 110, 801–821, 2012.

National Research Council: Surface Temperature Reconstructions for the Last 2000 Years, The National Academies Press, Washington, DC, 141 pp., 2006.

PAGES: Science Plan and Implementation Strategy, IGBP Report No. 57, IGBP Secretariat, Stockholm, 67 pp., 2009.

Pfister, C.: Monthly temperature and precipitation in central Europe 1529–1979: quantifying documentary evidence on weather and its effects, in: Climate since A.D. 1500, edited by: Bradley, R. S. and Jones, P. D., Routledge, New York, 118–142, 1992.

Shao, X.-M., Xu, Y., Yin, Z.-Y., Liang, E.-Y., Zhu, H.-F., and Wang, S.-Z.: Climatic implications of a 3585-year tree-ring width chronology from the Northeastern Qinghai-Tibetan Plateau, Quaternary Sci. Rev., 29, 2111–2122, 2010.

Shen, C.-M., Wang, W.-C., Gong, W., and Hao, Z.-X.: A Pacific decadal oscillation record since 1470AD reconstructed from proxy data of summer rainfall over Eastern China, Geophys. Res. Lett., 33, L03702, doi:10.1029/2005GL024804, 2006.

Wang, R.-S. and Wang, S.-W.: Reconstruction of winter temperature in east China during the 30 last 500 years using historical documents, Acta Meteorol. Sin., 48, 180–189, 1990.

Wang, S.-W., Ye, J.-L., and Gong, D.-Y.: Climate in China during the Little Ice Age, Quaternary Sci., 25, 54–62, 1998.

Wang, W.-C., Ge, Q.-S., Hao, Z.-X., and Zheng, J.-Y.: Rainy season in Beijing and Shanghai since 1736, J. Meteorol. Soc. Jpn., 86, 827–834, 2008.

Xoplaki, E., Luterbacher, J., Paeth, H., Dietrich, D., Steiner, N., Grosjean, M., and Wanner, H.: European spring and autumn temperature variability and change of extremes over the last half millennium, Geophys. Res. Lett., 32, L15713, doi:10.1029/2005GL023424, 2005.

Zhai, P.-M., Sun, A.-J., Ren, F.-M., Liu, X.-N., Gao, B., and Zhang, Q.: Changes of climate extremes in China, Clim. Change, 42, 203–218, 1999.

Zhang, D.-E.: Winter temperature changes during the last 500 years in South China, Chin. Sci. Bull., 6, 497–500, 1980.

Zhou, Q.-B., Wang, Z., and Zhang, P.-Y.: Reconstruction of annual winter mean temperature series in Hefei area during 1736 to 1991, Acta Geogr. Sin., 49, 332–337, 1994.