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Reconstructed May–July mean maximum temperature since 1745 AD based on tree-ring width of *Pinus tabulaeformis* in Qianshan Mountain, China

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ABSTRACT

A tree–ring–width chronology of *Pinus tabulaeformis* was developed from the Qianshan Mountain, Liaoning province, northeastern China. Based on the correlation between the ring width and instrumental data, a transfer function was designed and the May–July mean maximum temperature (MMT) from 1745 to 2012 was reconstructed. The reconstruction explains 42.7% of the instrumental variance during the calibration period (41.7% after adjusting for the loss of the degrees of freedom). The reconstructed MMT is similar to several observed MMT series and the temperature index in north-central China, which indicated that the decrease in summer temperatures in the 20th century was a large scale phenomenon. The reconstruction also showed that high MMT values corresponded to historical drought events in Liaoning. In addition, a spatial correlation analyses revealed that the MMT reconstruction is regionally representative. Significant 128.2-, 64.1-, 18.6-, 3.46-, 3.19-, 2.43-, 2.15- and 2.10-year cycles were detected in the reconstructed MMT series from Qianshan Mountain.

1. Introduction

Tree rings have been widely applied in global climate change studies because they offer precise dating, high continuity, high time resolution, and because they are widespread and easily replicated. There has been great progress in dendroclimatological research in China in the past twenty years. Most of the work has focused on the arid and semi-arid zone in northwestern China (Liu et al., 2001; Yuan et al., 2001; Liu et al., 2004; Li et al., 2007; Liang et al., 2008a; Liu et al., 2009b; Bao et al., 2012) and the Tibetan Plateau (Zhang et al., 2003; Liu et al., 2006, 2009a; Fang et al., 2010; Shao et al., 2010). Liu et al. (2009a) reconstructed the annual temperatures in the central-eastern Tibetan Plateau for the last 2485 years. Zhang et al. (2003) presented a 2326-year-long tree-ring width chronology and discussed the variation in the spring precipitation of the northeastern Tibetan Plateau. Shao et al. (2005) reconstructed the annual precipitation from July to June for the last 1000 years for Delingha and also established a 3585-year-long tree-ring width chronology based on samples from archaeological wood and living trees (Shao et al., 2010). Liang et al. (2009) investigated the variation in annual precipitation since 1770 AD for the western Qilian Mountains. Liu et al. (2004) reconstructed the precipitation for May–July in the Helan Mountain since 1726 AD based on latewood ring width.

Liaoning Province, located in northeastern China, is strongly influenced by the East Asian Summer Monsoon. Because of the interannual instability of the East Asian Summer Monsoon, frequent drought and flooding seriously affect agriculture, ecosystem and the hydrological cycle. For examples, the severe drought year (no rainfall for 47 days) occurred in Qianshan, Liaoning during May to July in 2000 caused seriously decreasing of agricultural output (Wang et al, 2005); The extreme wet year in August 1995 in Liaoning caused tremendous property damage (over US$ 60 billion in estimated) (Mu, 2007). Therefore, it is important to study past climatic conditions in more detail and predict future climatic trends in this area. Dendrochronology is regarded as a useful tool for studying climate in the past. However, dendroclimatological researches are relatively rare in northeastern China (Shao and Wu, 1997; Liu et al., 2009c; Chen et al., 2011; Bao et al., 2012) so far, which have prevented a deep understanding of past climate change in this area.

In this paper, we present a May–July mean maximum temperature reconstruction using the tree-ring width data beginning in 1745 AD from the Qianshan Mountain region in northeastern China. We also explore the potential relationships between the reconstructed temperature and large-scale climatic change.

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2. Materials and methods

2.1. Sites description and tree-ring data

The Qianshan Mountain, located in the central Liaoning province, China, has a warm temperate continental monsoon climate with four distinct seasons, with coinciding warm and rainy periods. The total annual precipitation is 640–880 mm, and the annual mean temperature is 6.3–7.0 °C. The Chinese pine (*Pinus tabulaeformis* Carr.) was collected, which is widely distributed on ridges and an important dominant evergreen species at the study sites. As studied (Xu, 1993), the cambial cell division of *Pinus tabulaeformis* trees start at the mean temperature 9.3 °C, and end at 15.9 °C. This temperature range in Qianshan region corresponds to the period of April to September. The sampling site Qianshan (QS) is located at 40°59′–41°01′N, 123°07′–123°08′E with elevation 500–600 m (Fig. 1). Two 5-mm increment cores were obtained from each of 40 trees. All the sampled trees grow on thin black soil with a discontinuous canopy.

2.2. Chronology development

According to the standard methods and procedures of dendrochronology, the pretreatment of the samples in the laboratory included drying, mounting and surfacing. All samples were cross-dated using a skeleton plot method (Stokes and Smiley, 1996), and then the tree-ring width was measured to within 0.01 mm using LINTAB tree-ring width equipment. The COFECHA program (Holmes, 1983) was used to control the quality of the cross-dating. Each individual ring was accurately associated with a calendar year.

To remove the undesirable age-related growth trends that are not related to climatic variations and to conserve the common signal at a low frequency, the tree-ring series were detrended and standardized by fitting either a straight line or a negative exponential function using the program ARSTAN (Cook and Holmes, 1986). The ARSTAN program could produce three chronologies: standard (STD), residual (RES) and autoregressive standard chronology (ARS). Because the STD chronology can retain all frequencies, we used the STD chronology to perform further analysis in this paper.

The statistical characteristics of the QS STD chronology are shown in Table 1. The expressed population signal (EPS), with a value of 0.95 for QS, is one of the criteria used to quantitatively evaluate the reliability of tree-ring chronologies. An EPS value of greater than 0.85 is generally considered to be an acceptable threshold for a reliable chronology (Wigley et al., 1984; Cook and Kairiukstis, 1990). The valid period of the chronology was assessed by the sub-sample signal strength (SSS) (Wigley et al., 1984). To ensure the reliability of the reconstruction, we used SSS with a threshold value of 0.85. The minimum sample depth was 10 trees starting in 1745 AD and then the expressed population signal (EPS) was 0.95. Fig. 2 shows the QS STD chronology and its Rbar and EPS parameters.

Table 1
Statistical characteristics of the QS standard chronology.

Statistical item	STD
Mean sensitivity	0.25
Standard deviation	0.31
Skewness	0.58
Kurtosis	0.34
First order autocorrelation	0.53
Mean correlation between all series	0.38
Mean correlation between trees	0.38
Mean correlation within a tree	0.66
Signal noise ratio	18.94
Expressed population signal (EPS)	0.95
%Variance in 1st PC	42.28
First year where SSS > 0.85(No. of trees)	1745(10)

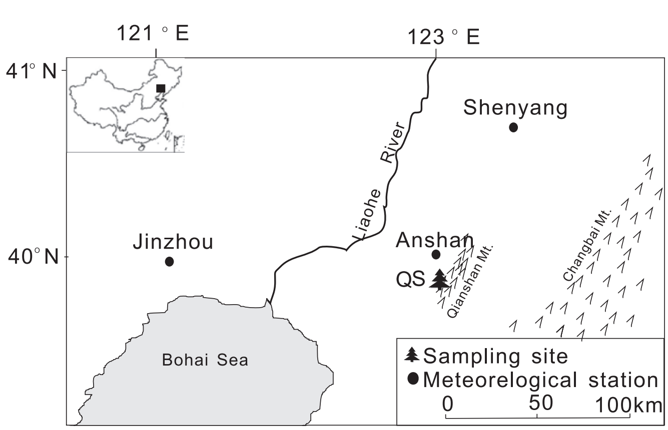

Fig. 1. Sampling site and nearby meteorological stations.

2.3. Climatic and PDSI data

There are three meteorological stations near the sampling sites: Shenyang (42°48′N, 123°24′E; elevation 42.0 m), Anshan (41°05′N, 123°00′E; elevation 65.9 m) and Jinzhou (41°08′N, 121°07′E; elevation 77.3 m) (Fig. 1). The record period of each meteorological station was from 1951 to 2012. Standard methods were used to test the homogeneity and randomness of the observed meteorological data (Potter, 1981; Peterson and Easterling, 1994; Easterling and Peterson, 1995), and the results showed that the temperature and precipitation data of the three meteorological stations were qualified for further analysis. The distributions of the monthly mean temperature, mean minimum temperature, mean maximum temperature and precipitation of each station were shown in Fig. 3. The monthly variation patterns for the four climate factors were almost synchronous among the three meteorological stations.

To better understand the regional climate characteristics, the meteorological data from the Shenyang, Anshan and Jinzhou stations were averaged to represent the regional climate condition. In the following section, the QS chronology and the averaged meteorological data were

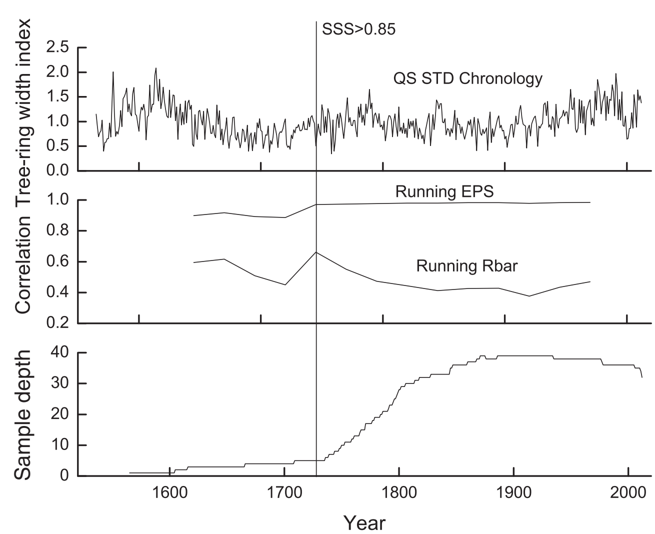

Fig. 2. A plot of the QS STD chronology, showing the expressed population signal (EPS), Rbar statistics and sample depth. (Rbar-average correlation between indices for each year over sequential time periods in length).