Journal of Arid Environments 127 (2016) 66–73

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Tree-ring reconstruction of January–March minimum temperatures since 1804 on Hasi Mountain, northwestern China

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A R T I C L E I N F O

Article history:
Received 19 December 2014
Received in revised form
15 August 2015
Accepted 29 October 2015
Available online xxx

Keywords:
Chronology
Climate reconstruction
Abrupt climate variability

A B S T R A C T

A new chronology was developed using *Pinus tabulaeformis* tree-ring data obtained from Hasi Mountain in northwestern China. On the basis of a correlation analysis between the tree-ring width and climate data, a January–March minimum temperature series from 1804 to 2009 was reconstructed. The tree-ring chronology explains 37.1% of the instrumental temperature variance during the period of 1958–2007. The temperature reconstruction showed warm intervals occurred in 1812–1826, 1831–1848, 1877–1885, 1898–1918, 1923–1936, and 1988–2007, while cold periods occurred in 1804–1811, 1886–1897, and 1941–1981. The warm and cold periods correspond to droughts and wet periods, respectively. A warming trend since the 1950s has been observed, which coincides with results from other reconstructions based on tree-ring data from the neighboring area. A spatial correlation indicates that the reconstructed temperature has a significant teleconnection with sea surface temperatures (SSTs) in the northern and eastern tropical Pacific and Indian Oceans. The results from power spectrum and correlation analysis suggest that the El Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO) and Arctic Oscillation (AO) can influence the winter temperature variation in northwestern China by controlling the strength of the East Asian Winter Monsoon (EAWM).

1. Introduction

In the context of global warming, temperature changes in past centuries have become of interest in recent decades. Prior studies have provided long-scale temperature variation information based on different climate proxies, such as ice cores (Yao et al., 2002), coral (Asami et al., 2013), stalagmites (Tan et al., 2013) and pollen (Eugene et al., 2012). Tree rings have also been used to reconstruct temperature variations over past centuries and millennia because of their precise dating and high resolution (Briffa et al., 1990; Cook et al., 1992; Yadav et al., 1999; Zhu et al., 2009, 2011; Zheng et al., 2013; Liu et al., 2013). Among these studies, seasonal or annual mean temperatures are commonly reconstructed, which demonstrate that climate warming over the past 100 years is unprecedented (Cook et al., 1992; Zhu et al., 2009). However, the former studies also suggest that the mean, minimum and maximum temperature changes may not be synchronized (Karl et al., 1993; Wilson and Luckman, 2002; Xie and Cao, 1996; Gou et al., 2008) and that the global warming over the past decades is mostly due to the faster rise of night or minimum temperatures (Karl et al., 1993).

In this paper, a tree ring with chronology, constructed from the living trees of *Pinus tabulaeformis* on Hasi Mountain, which lies on the boundary of China's northern deserts and the Loess Plateau, as well as the margin of the Asian summer monsoon region, are used to reconstruct the January–March minimum temperature histories for the last 200 years. The purpose in this study are to (1) examine the relationships between tree growth and climatic factors, (2) reconstruct and investigate temperature variability for the study area, and (3) discuss the regional response to the large-scale atmosphere-ocean circulation system.

2. Materials and methods

2.1. Study area

Hasi Mountain (104°18.67′–104°35.00′E, 36°58.33′–37°02.67′N) is located at the desert-loess transition zone in northwestern China

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http://dx.doi.org/10.1016/j.jaridenv.2015.10.020

with a peak elevation of 3017 m (Fig. 1). This region is characterized by a temperate semi-arid monsoonal climate with a mean annual temperature of 3–10 °C and an average annual precipitation of 350–410 mm, as recorded by nearby meteorological stations. The temperature is lowest in January with a mean minimum value of −12.3 °C and has a peak value of 28.7 °C in July. The precipitation is concentrated in the summer and early fall, with over 75% of the annual precipitation occurring during this period. On the Hasi Mountain, *P. tabulaeformis* is the main tree species and grows in an elevation zone of 2100–2700 m (Yang, 2003).

2.2. Tree-ring data and chronology development

Tree-ring cores were taken from living *P. tabulaeformis* trees at an elevation of approximately 2400–2700 m in August 2010. We obtained two tree-ring cores per tree or three cores from some older trees using an increment borer with a 5.3 mm inner diameter. A total of 78 samples were processed in the laboratory using standard dendrochronological techniques (Fritts, 1976). After cross-dating (Stokes and Smiley, 1968) with a skeleton plot and measurements, the dating accuracy and possible measurement errors were further verified using the COFECHA program (Holmes, 1983). Cores with ambiguous results and those too short were excluded from further analysis. Ultimately, 73 cores from 39 trees were selected for the development of the chronology.

The negative exponential or linear function was fit to each ring-width measurement series to remove the non-climatic growth trends related to age, size, and effects of stand dynamics (Cook and Briffa, 1990). A 67% cubic smoothing spline with a 50% cutoff frequency was also used when anomalous growth trends occurred. The individual indices were combined into site chronologies using a bi-weight robust mean designed to minimize the effect of outlier values. These analyses were all performed using the ARSTAN program (Cook, 1985).

2.3. Climate data

The three meteorological stations nearest the sample sites are Jingyuan (JY), Baiyin (BY) and Jingtai (JT) (Table 1). Although there are some differences in the elevations, the patterns of monthly temperature and precipitation at the three meteorological stations are almost identical during the instrumental period (Fig. 2). The three meteorological stations have similar distances to the sample sites. We used a method of arithmetic averages to develop a regional climate series. Given the various time spans of availability of the meteorological data, and to avoid depending on a single station, the common time span of 1958–2007 was used for the reconstruction analysis.

3. Results

3.1. Tree-ring chronology

The ring-width index and the number of samples are shown in Fig. 3. The mean sensitivity of the standard chronology is 0.35, indicating that the chronology exhibits inter-annual variation and contains strong environmental signals. The average correlation among the tree-ring series was 0.57, with a signal-to-noise ratio

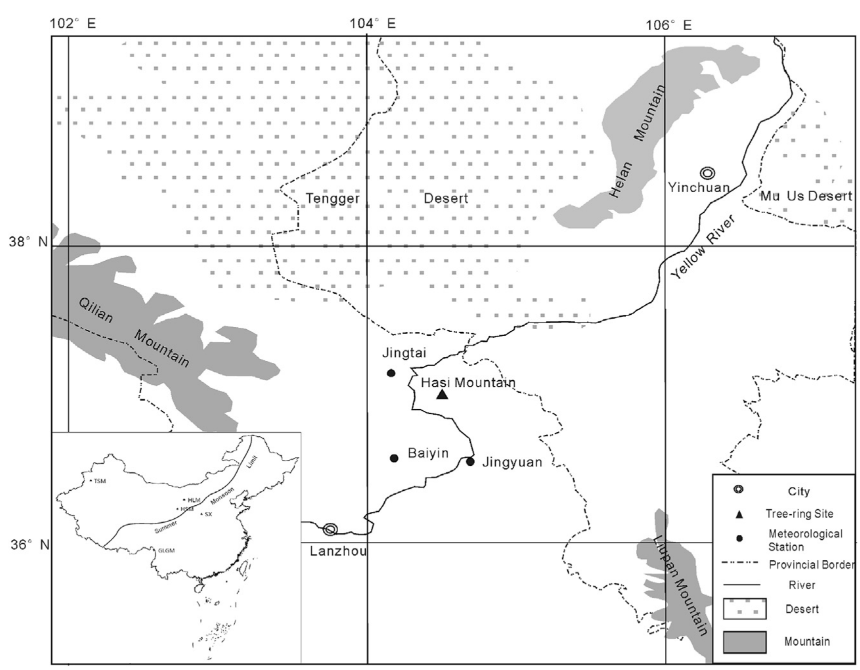

Fig. 1. The locations of sampling sites and meteorological stations.

Table 1
Information of meteorological stations.

Station name	Elevation(m)	Latitude	Longitude	Time span	Annual temperature (°C)	Annual precipitation (mm)
Jingyuan	1398.2	36.57°N	104.68°E	1951–2007	9.1	237.8
Baiyin	1710.8	36.55°N	104.18°E	1954–2007	8.4	201.4
Jingtai	1630.9	37.18°N	104.05°E	1958–2007	8.6	184.2