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# May–July mean minimum temperature variability in the mid-Qinling Mountains, central China, since 1814 CE

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ABSTRACT

A tree-ring width (TRW) chronology was developed from *Larix chinensis* Beissn at the divide sampling site in the mid-Qinling Mountains, central China. The relationships between tree radial growth and climate factors on several timescales (Daily, Pentad, Dekad and Month) were studied. Compared to precipitation, temperature shown stronger impacts on *Larix chinensis* Beissn on each timescales. Particularly, pentad was a more suitable scale for tree growth-climate response analysis. Significantly positive correlation was found between tree-ring index and the mean minimum temperature from May to July, i.e. 28 to 42 pentads ($r = 0.625$, $p < 0.001$). Based on this relationship, the May to July mean minimum temperature was reconstructed in the last 194 years, with an explained variance of 39.1% for the calibration period from 1957 to 2007. The results of leave-one-out tests showed that the reconstruction mode was stable and reliable. This minimum temperature reconstruction revealed that cold spans mainly occurred in 1816–1831, 1840–1852, 1879–1888 and 1976–1984, while warm spans prevailed in 1863–1878, 1889–1897, 1916–1932 and 2000–2007. Comparisons with other surrounding temperature series from tree rings, our reconstruction could provide a good regional representation of temperature change in the mid-Qinling Mountains. The reconstructed minimum temperature series was further verified by dryness-wetness index (DWI) sequence based on Chinese historical literature. Significant quasi-periodic signals at 32.2a, 20.5a, 8.9–13.1a and 2-8a suggested that temperature variability in the study area may associate with the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO).



## 1. Introduction

The global average surface temperature has increased by 0.85 °C from 1880 to 2012 and global warming has a significant impact on natural ecology and human living environment (IPCC, 2013). Global ecosystems are threatened by individual species' ecological function variations related to climate change (Parmesan, 2006). Both frequency and negative influence of extreme climate events including drought, flood, heat wave and cold wave have increased, and more attentions have been paid due to their significant and direct impacts on society and human beings (Hay and Mimura, 2010; Konisky et al., 2016; Stott, 2016). Compared to the global scale, the effects of climate change on the regional scale are receiving increasing attention, especially in those areas where the ecological environment is fragile and the capacity to respond to climate change is limited (IPCC, 2013). China has a vast area with diverse climate and environment. For instance, affected by the Asian monsoon activities, the frequent occurrence of droughts are in northern China and that of heavy rain and floods are in southern China. The Qinling Mountains (QLM) is an important dividing line of climate division between northern China and southern China, and it is also a sensitive area of climate change in China (Liu and Shao, 2000; Bao et al., 2015). Many factors such as Asian monsoon and westerly modulate the local climate in QLM. A recent study (Jiang et al., 2016) has reported that extreme warm indices significantly increased inferred from daily surface air temperature of 47 meteorological stations in the Qinling Mountains. Previous studies found that the rise in temperature is mainly due to an increase in night time temperature or daily minimum temperature

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during the latter half of the twentieth century (Easterling et al., 1997; Karl et al., 1993). The weather records showed that the increasing temperature in various places throughout China is mainly caused by of the rise at night time temperature (Zhai and Pan, 2003). Consequently, the study of minimum temperature variation cannot be neglected.

Due to the rich forest resources in QLM, palaeoclimatic studies based on forest vegetation materials have been widely carried out in the Qinling Mountains (Zhao et al., 2014; Wang et al., 2016). For example, connections of vegetation and climatic variations from a swamp sediment profile were performed for Qinling Mountains using pollen analysis (Zhao et al., 2014). Recently, based on the results of a sub-alpine lake on the highest mountain Taibai in QLM, environmental changes history over the past 5770 years were demonstrated and possible linkages between local climate fluctuations and larger-scale East Asian monsoon were discussed (Wang et al., 2016). Dendroclimatological studies also have been performed in this area (e.g. Liu and Shao, 2000; Wang and Bao, 2016). Liu et al. (2009a) reconstructed May to July mean temperatures for the northern QLM region; Liu et al. (2013) and Chen et al. (2015) found that droughts and broad-scale climate variability reflected by temperature-sensitive tree growth in QLM. However, the reconstructed climatic factors are mainly concentrated on the average temperature and precipitation (e.g. Shao and Wu, 1994; Garfin et al., 2005; Liu and Shao, 2000; Liu et al., 2001, 2009a, 2009b; Yang et al., 2013, 2016), minimum temperature variation inferred from tree-ring width is very rare in the mid-Qinling Mountains, China (Lei et al., 2016). Taking into account the huge geographical distribution of c.a.1500 km from east to west and diverse habitat of the Qinling Mountains, it is necessary to conduct more tree-ring researches for completely understanding the climate variability and environment change from this region. The present study aims to provide a long-term minimum temperature series obtained from *Larix chinensis* Beissn for lack of proxy data area of mid-QLM region. The connections between the minimum temperature, drought and remote climate forcing are explored. Our results could be helpful to mitigate the adverse effects of climate change on the Qinling Mountains and enhance regional response capacity to the warmer future as projected.

## 2. Materials and methods

### 2.1. Study area and tree-ring data

The study area is located in the mid-QLM, which is a transition zone between subtropical and warm temperate zone, humid and semi humid area (Kang and Zhu, 2007). On account of its geographical location and complicated topography, local climate characteristics are obvious and sensitive to climate changes (Zhou et al., 2011). The sampling site is Guangtou Mountain (GTM) (108°46′E, 33°51′N, elevation 2600–2750 m) (Fig. 1). Tree-ring width chronologies shown in Fig. 2 were used in this study derived from 44 cores of Larch tree (Liu et al., 2009b). Samples dating, quality controlling and chronologies establishing were performed utilizing COFECHA program (Holmes, 1983) and ARSTAN program (Cook and Kairiukstis, 1990). Specific parameters and details are described in the literature, i.e. Liu et al., 2009b. Standard chronology (STD) was selected for further analysis because it contains more information than residual chronology (RES).

### 2.2. Meteorological data

The meteorological records were obtained from the China Meteorological Date Sharing Service System (http://cdc.cma.gov.cn). Considering the regional representation of climate data, the nearest two meteorological stations, i.e. Xi''an station (34°18′N, 108°56′E, elevation 400 m) and Foping station (33°32′N, 107°59′E, elevation 1192 m, covering the period of 1957–2007) were selected, and records included daily mean temperature (Tmean), daily mean minimum temperature (Tmin), daily mean maximum temperature (Tmax), and daily precipitation (P). The other scale data were calculated from daily date. Similar variations of temperature and precipitation existed in both meteorological stations (Fig. s1).

Considering the distance between meteorological stations and tree-ring sampling site, Foping station was used for further analysis in current research for they had similar stand environment. To assess the regional significance of our reconstruction, the dryness-wetness index (DWI) data of Xi'an and Hanzhong (HZ) stations, were used for comparison. The DWI records are based on Chinese local annals and many other historical writings, and published by the Chinese National Meteorological Administration (CNMA, 1981).

### 2.3. Statistical methods

Daily data were transformed into different timescales data (i.e. pentad, dekad and month). There is an extra day in a leap year: February 29. The total precipitation of February 28 and 29 was used as the February 28 precipitation, and the average temperature of February 28 and 29 was used as the February 28 temperature, for 365 days. For example, the first pentad is January 1th to 5th, and the last pentad is December 27th to 31th, in all 73 pentads in a year. There are three dekads in a month, 36 dekads, and 12 months in a year (Fig. 3).

The responses of tree radial growth to climate on different scales were studied by correlation analysis between climatic factors and chronology through the software SPSS Statistical 22. Linear regression equation was designed to reconstruct the past climate history. And the reliability of this model was verified by several regular tests. Leave-one-out verification method (Michaelsen, 1987) was used to validate the calibration function. The evaluative statistics included Pearson's correlation coefficient (r), the product-mean test (PMT), the raw sigh data (ST) and the first-difference sigh data (ST1), the reduction of error (RE) (Cook et al., 1999). The power spectrum analysis was conducted to identify the periodicity in the reconstructed series. Power spectrum is one of the main contents of digital signal processing. It mainly studies the characteristics of signals in frequency domain (Wei, 2007).

## 3. Results

### 3.1. Tree growth-climate response

Fig. 4 showed the results of correlation analysis between the tree-ring index of STD chronology and the temperature and precipitation at different timescales. In general, the correlation coefficients between the tree-ring index and Tmin were stronger than those between chronology and Tmean or Tmax. On the month scale, the relationship between ring-width index and temperature from January to March and from May to July exceeded the significant level of 0.05, but there is inconsistent on the pentad scale. This result could indicate that more information or details of tree growth responding to climatic factors appear on the pentad scale. The correlations between the tree-ring index of STD chronology and precipitation were weak and not statistically significant in most months on the month scale, except for a positive correlation in the previous October and current August, but the relationship was not significant. On the pentad scale, only the precipitation in early April and early September reached 0.05 significant levels. Therefore, compared with precipitation, temperatures were more crucial to