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A 225-year long drought reconstruction for east Xinjiang based on Siberia larch (*Larix sibirica*) tree-ring widths: Reveals the recent dry trend of the eastern end of Tien Shan

Feng Chen [a, b, *], Yu-jiang Yuan [a], Shu-long Yu [a], Tong-wen Zhang [a], Hua-ming Shang [a], Rui-bo Zhang [a], Li Qin [a], Zi-ang Fan [a]

[a] *Key Laboratory of Tree-ring Physical and Chemical Research of China Meteorological Administration/Xinjiang Laboratory of Tree-ring Ecology, Institute of Desert Meteorology, China Meteorological Administration, Urumqi, 830002, China*

[b] *MOE Key Laboratory of Western China's Environmental Systems, Collaborative Innovation Centre for Arid Environments and Climate Change, Lanzhou University, Lanzhou, 73000, China*

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ABSTRACT

A tree-ring width chronology developed from a site of *Larix sibirica* at the eastern end of Tien Shan was employed to study the drought variability of east Xinjiang. The drought reconstruction spanning 1785–2009 was developed by calibrating tree-ring data with standardized precipitation-evapotranspiration index (SPEI), an index indicating regional moisture conditions. The SPEI reconstruction accounted for 45.8% of actual October–August SPEI variance during their common period (1957–2009). Wet periods with SPEI above the 225–year mean occurred around 1785–1799, 1821–1833, 1842–1858, 1864–1873, 1887–1898, 1905–1925, 1937–1948, 1954–1962, 1969–1983 and 1991–1993, while dry periods (SPEI below the mean) occurred in 1800–1820, 1834–1841, 1859–1863, 1874–1886, 1899–1904, 1926–1936, 1949–1953, 1963–1968, 1984–1990 and 1994–2009. There was an aridity aggravation trend since the mid-1980s in east Xinjiang. Our results also suggest that east Xinjiang was influenced by the interactions between the Asian monsoon and the Westerlies circulations.

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1. Introduction

The Tien Shan is one of the largest mountain ranges in central Asia, where China, Kyrgyzstan, and Kazakhstan come together. It plays an important role in the climate and ecosystem of central Asia. East Tien Shan within Xinjiang is one of the driest regions in Tien Shan, and meets the Altay Mountains of Mongolia in the east. Unlike other Tien Shan regions, presently, the eastern end of Tien Shan is covered by widespread larch forests. Similar to the growth patterns of Siberia larch (*Larix sibirica*) in the Altay region (Davi et al., 2009; Chen et al., 2012), the growth of Siberia larch at the upper forest border was negatively correlated with spring, summer and annual mean precipitation, while winter and spring precipitation had a great positive influence on tree-growth at the lower forest border (Peng et al., 2006). Thus, tree-ring data of Siberia larch from the eastern end of Tien Shan has a great potential for dendroclimatological study. However, to date, there have been few studies reconstructing drought variations and exploring dynamics of drought variability at the eastern end of Tien Shan within east Xinjiang using tree-ring records (Yuan and Li, 1994; Peng et al., 2006).

Here, we present a tree-ring based standardised precipitation-evapotranspiration index (SPEI) reconstruction for east Xinjiang spanning 225 years. This study is the first tree-ring based SPEI reconstruction, which also identifies dry and wet periods for east Xinjiang over the past two centuries. In order to achieve these two major goals (i.e., SPEI reconstruction and identification of dry and wet periods), it was necessary to develop the precipitation/drought sensitive tree-ring chronologies at the lower forest border, to identify the impact of extreme drought on tree growth. This study is also important because it was carried out on the only natural Siberia larch forests in Tien Shan, which is also the south boundary of natural distribution of Siberia larch in Xinjiang. The knowledge

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* Corresponding author. Key Laboratory of Tree-ring Physical and Chemical Research of China Meteorological Administration/Xinjiang Laboratory of Tree-ring Ecology, Institute of Desert Meteorology, China Meteorological Administration, Urumqi, 830002, China.
E-mail address: feng653@163.com (F. Chen).

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gained is important for the sustainable evolution of fragile Siberia larch ecosystems in Xinjiang.

2. Materials and methods

2.1. Tree-ring chronology development

Field work for this study was carried out in 2009. The sampled tree-ring site (TAS, 43°15′ N, 93°50′ E, 2300 m a.s.l.) lies at the eastern end of Tien Shan in east Xinjiang, and has a large natural forest with minimal human disturbances (Fig. 1). The soil at TAS site is thin and rocky. The dominant tree species is Siberia larch, accompanied by Schrenk spruce (*Picea schrenkiana*). The canopy coverage of the sampled trees was less than 30%. Siberia larch is almost exclusively found on southerly slopes along an elevation zone of 2200–2850 m above sea level. The larch forest in the TAS site is nearly mono-specific, commonly with simple open-canopy structure. East Tien Shan also represents the southern limit of Siberia larch distribution in Xinjiang. Two increment cores were extracted from most trees, with one core from some younger trees.

After mounting and progressively sanding to >320 grit, all the cores were cross-dated with a skeleton plot (Stokes and Smiley, 1968) and subsequently measured to ±0.001 mm precision using a Velmex measuring system. To ensure exact dating for each annual ring width, the quality of visual cross-dating was further checked using the COFECHA program (Holmes, 1983). The chronology was developed using the ARSTAN program (Cook and Holmes, 1986). To remove non-climatic trends and retain as much climatic signal as possible, conservative detrending methods (negative exponential curve fits) was used to detrend each cores (Fritts, 1976). The variance in chronology was stabilized in the chronology compilation process with the Briffa Rbar-weighted method (Osborn et al., 1997). To evaluate the reliability of the chronology, the 50-year moving Expressed Population Signal (EPS) with a 25-year lag was calculated (Wigley et al., 1984).

2.2. Climate data and statistical analysis

The instrumental climate data covering the period 1957–2012 were obtained from the Balikun climate station. At the meteorological station in Balikun (43°36′N, 93°00′E, 1650.9 m a.s.l.), January (mean temperature of −17.8 °C) and July (18.1 °C) are the coldest and the warmest month, respectively (Fig. 2). The multi-year mean of annual precipitation amounts to 219.3 mm, with 70.4% of the annual precipitation falling during the growing season approximately from April to August. The monthly SPEI data were calculated based on the climate data from the Balikun climate station by using the SPEI calculator (Vicente-Serrano et al., 2010). As the growth of tree may be affected not only by the climatic conditions of the current growing season but also by those of the previous growing season (Fritts, 1976), climate data used for the correlation analysis included monthly mean temperature and total monthly precipitation over a span of 15 months (previous July to current September).

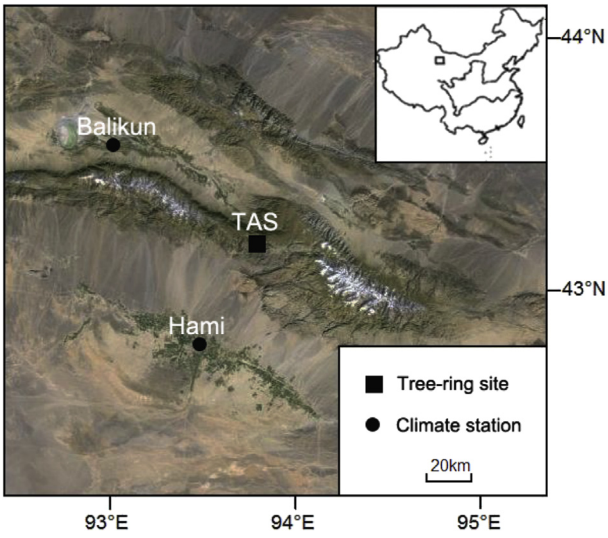

Fig. 1. Location map of sampling site and meteorological stations.

The ‘leave-one-out’ method was used to evaluate the goodness-of-fit of the model (Blasing et al., 1981). The testing statistics used included the reduction of error (RE), coefficient of efficiency (CE), the sign test, the first-order sign test and the Pearson's correlation coefficient (Cook and Kairiukstis, 1990). To highlight low-frequency climate signals, climate reconstructions were smoothed with some low-pass filters (10-year). In accordance with Chen et al. (2011), we defined extremely dry years as those with SPEI $\leq$ 2 standard deviation (SD) below the mean, and extremely wet years $\geq$ 2 SD above the mean. To illustrate that our SPEI reconstruction reflect large-scale drought variability, we correlated the SPEI reconstruction with the gridded SPEI dataset (Vicente-Serrano et al., 2010) for the period 1957–2009. The analyses were conducted using the KNMI climate explorer (http://climexp.knmi.nl).

3. Results

3.1. Correlation analyses and SPEI reconstruction

To ensure the reliability of the climate reconstruction and utilize the maximum length of the residual chronology, the Expressed Population Signal (EPS) with a threshold value of 0.8 was selected to evaluate the reliable time span of the residual chronology. This threshold corresponds to a minimum sample depth of six cores (from AD 1785) (Fig. 3). Tree-rings were positively correlated with precipitation and negatively correlated with temperature (Fig. 4). Much higher positive correlations were seen between tree rings and SPEI in current growing season, particularly from January to August. As seasonally averaged climate data has a larger representativeness of climate condition than just one single month (Fritts, 1976), different seasonal combinations of SPEI were tested for drought reconstruction. The highest correlation is found between the residual chronology and October–August SPEI ($r = 0.677$, $P < 0.001$).

Based on the above climate response analysis results, a simple linear regression model ($\text{SEPI} = -0.915 + 0.929\text{TAS}$) was used to reconstruct October–August SPEI for east Xinjiang. The model explained 45.8% of the total variance of the instrumental records during 1957–2009 (Fig. 5), and 42% in the leave one-out cross validation. The positive RE and CE indicates good predictive skill of the regression model. For additional verification, the sign test and first-order sign test were both found to be significant at the 0.001 level (Table 1).

Table 1
Leave-one-out cross-validation statistics for reconstruction of October–August SPEI for east Xinjiang based on tree-ring index.

R	r^2	F	Sign test	First-order sign test	RE	CE
0.648	0.420	42.260	$13^-/39^+$	$13^-/38^+$	0.394	0.387

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