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ORIGINAL ARTICLE

Precipitation reconstruction for the southern Altay Mountains (China) from tree rings of Siberian spruce, reveals recent wetting trend

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ABSTRACT

We developed six tree-ring width chronologies of Siberian spruce (*Picea obovata*) from the low elevation forest of the southern Altay Mountains in northern Xinjiang, China. Although the six chronologies come from different sampling sites, significant correlations existed among the chronologies ($r \geq 0.477$), and the first principal component (PC1) accounted for 72.2% of total variance over their common period 1825–2010. Correlation response analysis revealed that radial growth of Siberian spruce is mainly limited by a 12-month precipitation starting from July of the previous year to June of the current year. We therefore developed a July–June precipitation reconstruction spanning 1825–2009, which explained 65.5% of the instrumental variance for the period 1962–2009. The information of our precipitation reconstruction suggested that dry conditions existed for the periods 1829–1838, 1852–1855, 1876–1888, 1898–1911, 1919–1923, 1932–1936, 1943–1955, 1963–1968, 1973–1984 and 2007–2009, and wet conditions for the periods AD 1825–1828, 1839–1851, 1856–1875, 1889–1897, 1912–1918, 1924–1931, 1937–1942, 1956–1962, 1969–1972 and 1985–2006. Spatial climate correlation analyses with gridded land surface data revealed that our precipitation reconstruction contains a strong precipitation signal for the Altay Mountain ranges. Our reconstruction agreed with the moisture-sensitive tree ring width series of Siberian larch from the Altay Mountains of Mongolia on a decadal timescale. In addition, in contrast to a drying trend in north central China, a clear wetting trend has occurred in the southern Altay Mountains since 1980s.

Introduction

The Altay Mountains is a region with complex physical geography, climate interactions, high level of endemism in the flora and fauna, and a number of coniferous species preserved in natural ecosystems. Some of the most interesting habitats include the treeline forests. These are often dominated by centuries-old trees with high potential for the development of centennial-length tree-ring chronologies. Based on tree rings of Siberian larch (*Larix sibirica*), a number of dendroclimatic reconstructions for the Altay Mountains have been developed in recent decades (Ovtchinnikov et al., 2000; Frank et al., 2007; Myglan et al., 2008; Zhang et al., 2008; Davi et al., 2009; Sidorova et al., 2012; Chen et al., 2012). These studies have clearly demonstrated the potential for using Siberian larch to better understand past trend in climate, but no study has focused on the strength and clarity of the climatic response of Siberian spruce (*Picea obovata*) that dominate low elevation forests of the Altay Mountains.

Some studies have caused much debate over climate change in the 20th century and especially about unprecedented warmth after the mid 1980s (Yuan et al., 2004; Shi et al., 2007; Chen et al., 2013a). The regional distribution of the increased extreme rain and attribution of precipitation variability in the arid Central Asia to specific climate forcing (e.g. global warming) are still uncertain, and increasing the confidence of future projection of rainfall pattern remains a challenge. The tree-ring width and density chronologies

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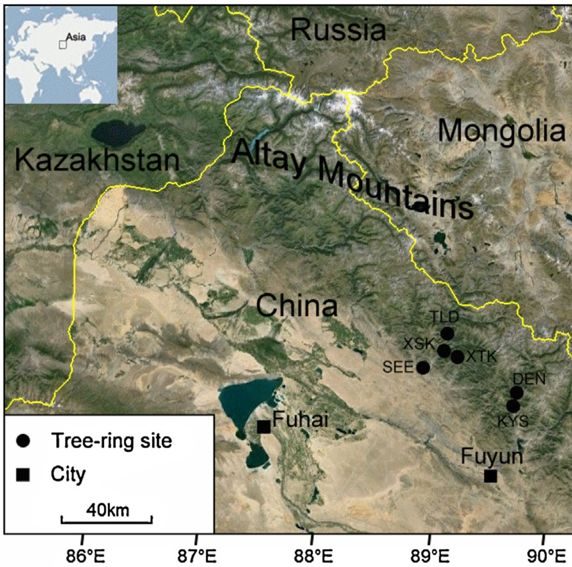

Fig. 1. Location map of sampling sites and meteorological station.

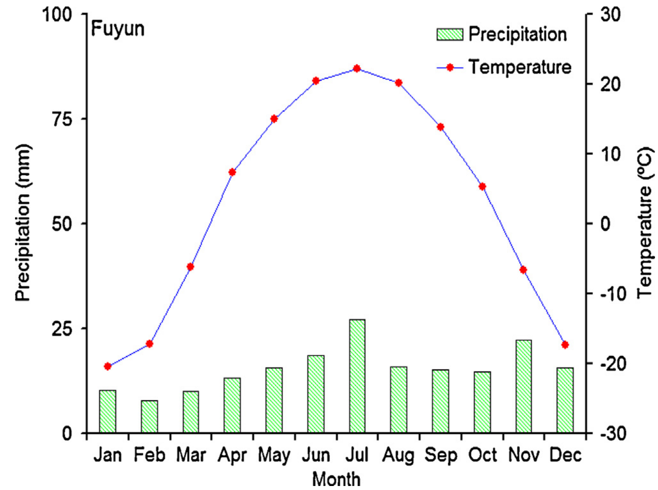

Fig. 2. Mean temperature and precipitation at Fuyun, based on long-term averages (1962–2009).

provide a valuable tool for understanding of local climate change (Chen et al., 2013b). In this context it is of crucial importance to construct long and reliable tree-ring chronologies based on the different tree-ring parameters, particularly for regions where such records are scarce. In the present study, we developed tree-ring width chronologies of Siberian spruce trees grown in the low elevation area of the southern Altay Mountains (China). The results of climatic response are used to assess the usefulness of Siberian spruce for paleoclimate studies. Based on the network of tree-ring width chronologies, a reconstruction of annual precipitation spanning AD 1825–2009 is developed. We also compared the results of this study with those of the previous study (Davi et al., 2009; Chen et al., 2012) to assess the common climate signals of the Altay Mountains.

Materials and methods

Study area

The study was conducted in Fuyun and Fuhai counties, located in the southern Altay Mountains, northern Xinjiang, China (Fig. 1). The study area is situated in the transitional zone from plateau in the east to plain in the west in terms of topography. Elevation in the study area ranges from 500 to 3000 m. The climate is characterized as temperate continental with short, cool summers and long, severe winters. The climatic conditions are influenced by arctic air masses, which come from the Arctic Ocean and move across the Ural Mountains without any topographic barrier far away into Siberia and the Altay Mountains. The mean annual precipitation is about 186.4 mm and the mean annual temperature is about 3.0 °C. Snowfall usually lasts 6 months (from October to March). July is the hottest month (average temperature 22.2 °C) while January is the coldest month (average temperature −20.5 °C). This area is one of the coldest places in China during the winter. Permafrost is well represented in this area and seasonal thawing of soil ice does not exceed 50–200 cm in depth.

In the study area, conifer forests above 2200 m in elevation are dominated by Siberian larch which usually forms single-species stands. Between the elevation of 1500 and 2200 m forests become dominated by Siberian spruce. Subalpine meadow occurs above 2700 m a.s.l. The cores of Siberian spruce were collected from six low elevation sites (<1700 m). At these sites, as the indicators of drought stress, open-canopy spruce trees with sparse vegetation grow on thin or rocky soils. In combination, these six sites provide 315 samples taken from 169 trees (Table 1).

Data collection and chronology development

Increment cores were collected at breast height from dominant trees using an increment borer. We employed standard dendrochronological techniques in the processing of tree cores (Fritts, 1976; Cook and Kairiukstis, 1990). Ring widths were measured using a Velmex measuring system with accuracy of 0.001 mm. A thorough check was made of the strength of the cross matching between trees using the computer program COFECHA (Holmes, 1983). The data were then standardized based on the negative exponential function, using ARSTAN software (Cook, 1985), in order to remove the age-related growth trends and preserve the climate signal. The final site chronologies were computed by calculating bi-weighted robust means of annual tree-ring indices. We computed several statistical parameters commonly used in dendrochronology from the non-standardized tree-ring width series. The mean sensitivity (MS) measures year-to-year variation in tree-ring width and is thus considered an estimate of the extent to which the chronology reflects local climate variation (Cook and Kairiukstis, 1990). The first-order autocorrelation (first AC) reflects the influence of previous year's growth on current growth. The expressed population signal (EPS) quantifies the degree to which the constructed chronology portrays the hypothetically perfect one (Wigley et al., 1984). We used an EPS value of 0.85 as a threshold for the reliability of our chronologies.

Meteorological data and statistical analysis

Instrumental climate records of Fuyun (1962–2009) were obtained from the China National Climatic Data Center (Fig. 2). Bootstrapped correlation functions were computed using the software DENDROCLIM2002 to explore the climate-growth relationships (Biondi and Waikul, 2004). A 95% confidence level criterion was used to determine the statistical significance. The ring-width chronologies were compared with a 15-month window of climate data spanning the period from previous July through September of the current growing season.

To assess the common growth forces among the individual sites of the southern Altay Mountains, correlation matrix and principal