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Early summer temperature changes in the southern Altai Mountains of Central Asia during the past 300 years

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A B S T R A C T

June–July mean temperature was reconstructed back to 1698 for the southern Altai Mountains in eastern Central Asia using four temperature series based on tree-ring widths. The reconstruction explains 48% of the variation in the observed temperature from 1962 to 2003. Warm periods occurred during 1714–1732, 1753–1776, 1800–1840, 1866–1886, 1893–1911, and 1943–1969, while the periods of 1708–1713, 1733–1752, 1777–1799, 1841–1865, 1887–1892, 1912–1942, and 1970–1993 were relatively cold. Power spectral and wavelet analyses demonstrated the existence of significant 50-, 14-, 2.8-, and 2.5-year cycles of variability. The results of a spatial correlation analysis suggested that this temperature reconstruction contains climatic signals for a large area of Central Asia. After employing a 21-year low-pass filter, the coherence of the newly reconstructed series with a regional temperature reconstruction for Central Asia and also with a local temperature reconstruction for the Zajsan Lake area of East Kazakhstan indicates that our temperature reconstruction captures broad-scale regional climatic variations in the low-frequency domain.

1. Introduction

Most meteorological records span less than 100 years and do not adequately describe past climatic changes. Therefore, climate variations on decadal to centennial scales are usually analyzed using various climatic proxies, such as tree rings, ice cores, loess sediments, lake sediments, stalagmites, deep-sea sediments, and historical records. Because of their precise dating, annual resolution, and comparability with recorded meteorological data, tree-ring data are regarded as one of the best proxy sources of information for paleoclimatic studies. Climatic reconstructions based on tree-ring data can extend our knowledge of climatic variability back hundreds or even thousands of years (Zhang et al., 2003; Liang et al., 2007; Cook et al., 2010; Büntgen et al., 2011; Esper et al., 2012; Liu et al., 2013).

Since the early 2000s, tremendous progress has been made in dendroclimatology in China regarding the increases of the spatial coverage of tree-ring sampling sites. These achievements have provided opportunities to describe local to regional climatic variations on annual timescales (Yang et al., 2009; Fang et al., 2010). The development of long or super-long chronologies using subfossil, archaeological, and living-tree juniper samples from the Tibetan Plateau is critical for both presenting the long-term climatic variability and revealing climatic forcing in the 20th century (Liu et al., 2009; Shao et al., 2010; Yang et al., 2014). Furthermore, climatic reconstructions based on tree-ring data have been linked to large-scale climate patterns to reveal climatic regimes, such as the Asian monsoon (Zhu et al., 2009), North Atlantic Oscillation (Zhang et al., 2013a), and Atlantic Multidecadal Oscillation (Wang et al., 2014).

In this paper, we present a reconstruction of early summer temperature for the southern Altai Mountains using temperature

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series based on tree-ring data from earlier studies. We compare the new reconstruction with a gridded meteorological dataset and other proxy records to assess the common climatic signals.

2. Regional setting

The Altai Mountains represent one of the most prominent mountain ranges in Central Asia. The range merges with the Sayan Mountain range in the east and its southeastern extension becomes a different range, called the Gobi Altai. The Altai Mountain range is divided into four parts politically: the Russian Altai in the north, Mongolian Altai in the east, Kazakhstan Altai in the west, and Chinese Altai in the south. The vegetation in the Altai Mountains reflects the North–South gradients of decreasing moisture and increasing temperature and the West–East gradients of decreasing moisture and increasing continentality. Although the Altai Mountain range is situated mostly within the latitude of zonal forest-steppe, its relief promotes the expansion of mountain forests.

The study area considered in this paper is located in the southern Altai Mountains and includes the entire Chinese Altai and the southeastern Kazakhstan Altai. The continental climate of the region is characterized by long and severe winters and cool, short summers; spring and autumn seasons are not obvious. Mean annual temperature is 3.7 °C and the minimum and maximum temperatures are −60 and 40 °C, respectively. The total annual precipitation varies from 500 to 700 mm. The potential annual evaporation is 1814.9 mm. The mean annual frost-free season persists for 131 days. In winter, snow cover is deep and snow damage frequent (Li et al., 2006).

3. Methods and materials

3.1. Tree-ring width based temperature reconstructions

Systematic dendroclimatological studies of the Altai Mountains began in 1980 (Zhang et al., 2008). Since then, many dendroclimatological studies have been performed in the western (Shang et al., 2011), middle (Sidorova et al., 2012), and eastern (Davi et al., 2009) Altai Mountains. Most of these studies have focused on the development of tree-ring chronologies and the response of tree growth to climate (Panyushkina et al., 2005; Zhang et al., 2007; Shang et al., 2010a; Hu et al., 2011; Li et al., 2011; Myglana et al., 2012; Chen et al., 2012a). However, these studies have primarily concentrated on reconstruction of the local paleoclimate (Zhang et al., 2008; Shang et al., 2010b, 2011; Hu et al., 2012a).

This study employed four temperature series based on tree-ring widths to reconstruct temperature variances for the southern Altai Mountains (Fig. 1). Further details including information on the study area, explained variance, and lengths of the series are presented in Table 1. The locations of the study area, meteorological stations, and tree-ring sampling sites are shown in Fig. 2. The Siberian Larch (*Larix sibirica*), trees sampled in previous studies are distributed widely throughout the Altai Mountains. Shang et al. (2011) developed one chronology using a linear regression function or a negative exponential function, applied to each tree-ring-width measurement and based on 50 cores from 30 trees, reconstructed the June mean temperature series for the eastern Kazakhstan Altai (EKA). Zhang et al. (2008) developed five chronologies using 100–150-year cubic smoothing splines, applied to two chronologies that were based on 107 cores from 51 trees, reconstructed the May–September mean temperature series for the western Chinese Altai (WCA). Shang et al. (2010b) developed three chronologies using a linear regression function or a negative exponential function, applied to each tree-ring-width measurement and based on 170 cores from 91 trees, reconstructed the June mean temperature series for the middle Chinese Altai (MCA). Hu et al. (2012b) developed eight chronologies using 120-year cubic smoothing splines, applied to one chronology that was based on 50 cores from 28 trees, reconstructed the June–July mean temperature

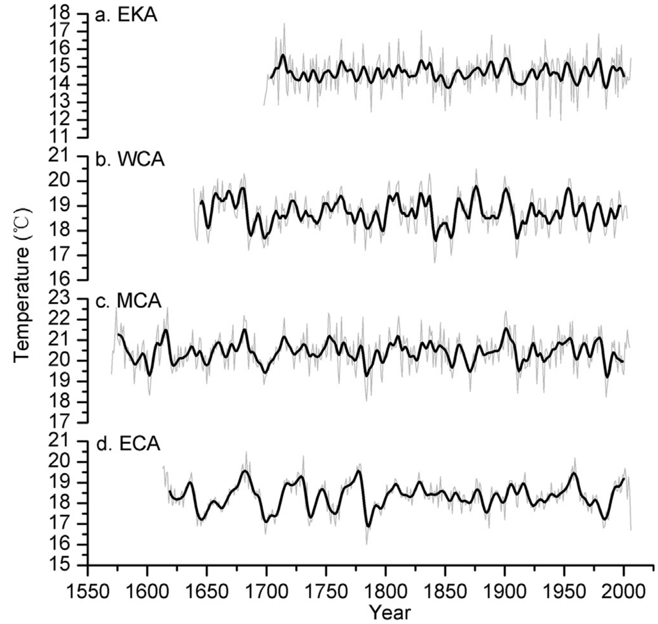

Fig. 1. (a) June mean temperature series for the eastern Kazakhstan Altai since 1698, (b) May–September mean temperature series for the western Chinese Altai since 1639, (c) June mean temperature series for the middle Chinese Altai since 1570, (d) June–July mean temperature series for the eastern Chinese Altai since 1613. Thin and thick lines represent the reconstructed temperature indices and their low-pass components using 13-year reciprocal filters, respectively.

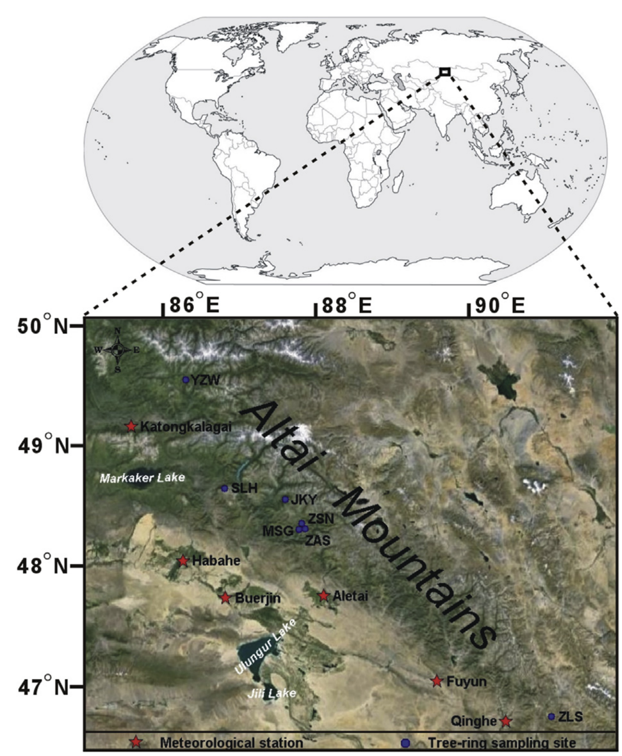

Fig. 2. Locations of the meteorological stations and the *Larix sibirica* Ledeb. tree-ring sampling sites in the southern Altai Mountains.